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STRATEGIC AIRLIFT: U.S. TO EUROPE.

Master's Thesis,

Eric Kalei Holck / Captain, USAF
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This thesis studies the problem of determining wartime
military airlift capability and factors within the military
airlift system which produce significant changes in system capa-
bility as measured in tons of cargo delivered after 30 days of
system operation. The airlift mission is set in a scenario which
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To examine the performance of the airlift system, a simulation model was created using the SLAM simulation language. This model encompasses the four major subsystems within the airlift system; these subsystems are aircrew, maintenance, supply, and aerial port. These subsystems employ resources which are pooled at two locations (one in the United States, and one in Europe).

A five-factor, two-level factorial design is employed to reveal those factors that produce significant changes in system capability. A total of 32 simulations were performed and the results were subsequently run through an analysis of variance (ANOVA) algorithm. The five factors investigated are: time to spare parts depletion; resupply time distributions; number of C-141s; number of cargo loading equipment; and the cargo load availability rate. The results of the ANOVA indicate that only the time to spare parts depletion (a supply function) and the number of C-141s produce significant changes to the airlift system capability. Beyond the conclusions drawn from these specific results, this thesis also illustrates the viability of an aggregate airlift system model as a useful tool in analyzing current and future airlift capability.

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STRATEGIC AIRLIFT: U.S. TO EUROPE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Eric Kalei Holck, Captain, USAF
Robert W. Ticknor, Captain, USAF

Graduate Strategic and Tactical Sciences

March 1981

Preface

This thesis was pursued as a result of a growing interest in the airlift community to analyze airlift capabilities by using computer simulation. Because of this interest in simulation, a majority of the research effort was spent at HQMAC/XPS, where Mr. Tom Kowalski and his MACRO staff contributed significantly to achieving a firm direction early in the course of this thesis effort.

As is the case with any project this size, the final product is but a culmination of the contributions from many people who deserve much more than the acknowledgements offered here. Many thanks go to LTC Tom Clark for his technical help as a thesis advisor and for his advise on the problems that reach beyond the writing of a thesis. Also, many thanks go to Cpt. Phil Richard for his interest and support in this thesis, and to Ms. Phyllis Reynolus, who did an outstanding job in typing this manuscript.

Of course, not enough can be said of the love, sacrifice, and support of our wives, Kathy and Jenny. For the many weeks of not having a husband home at night, of spending weekends alone with the children, and for typing the rough drafts, we thank them. Truly, this thesis is as much a result of their efforts as it is of anyone else.

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Abstract

This thesis studies the problem of determining wartime military airlift capability and factors within the military airlift system which produce significant changes in system capability as measured in tons of cargo delivered after 30 days of system operation. The airlift mission is set in a scenario which requires the reinforcement of Western Europe against a Warsaw Pact attack. This reinforcement is provided by C-141 and C-5 aircraft.

To examine the performance of the airlift system, a simulation model was created using the SLAM simulation language. This model encompasses the four major subsystems within the airlift system; these subsystems are aircrew, maintenance, supply, and aerial port. These subsystems employ resources which are pooled at two locations (one in the United States, and one in Europe).

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STRATEGIC AIRLIFT: U.S. TO EUROPE

I. Introduction

Background

Strategic airlift plays a large role in current U.S. strategy. Increased emphasis is being given to rapid deployment and mobility of forces in discussions which deal with the U.S. ability to keep its international commitments. Of the many commitments the U.S. has, the most demanding one is the defense of Europe (Ref 7:198). Further, the need to reinforce Western Europe against a Warsaw Pact attack is considered the most plausible major contingency that could arise (Ref 7:9). For these reasons, it is appropriate to direct a study of strategic airlift towards the European theater.

The problem of strategic airlift from the U.S. to Europe has its roots in the North Atlantic ship convoys used in World War II. The objective then was to move as much tonnage of war material as possible to Europe. Transit time was a factor, but it was generally not the key factor as it became obvious that the war was going to last for quite sometime. In these modern days, however, transit time has evolved to become a critical factor in the resupply and defense of Europe.

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The Soviet and Warsaw Pact forces are composed of highly mobile fighting units capable of spanning large ground distances per day (Ref 7:100). The NATO forces defending Western Europe must be ready to meet such an adversary. One strategy for successful defense immediately comes to mind: defensive preparedness can be established by maintaining large military forces in key positions while also stockpiling substantial War Reserve Materiel (WRM). Unfortunately, this strategy has proven to be politically and economically untenable (Ref 8:3) and an alternative strategy must be employed.

The alternative strategy employed by the U.S. is to maintain a force in Europe which (along with other NATO forces) is capable of a short-term holding action against an invasion. As such, the U.S. forces in Europe are relatively small and large WRM stockpiles do not exist. Additionally, even when the in-place U.S. forces are combined with all other NATO forces, the total defending force of Western Europe remains outnumbered and outgunned (see Figure 1). Therefore, inherent to the current strategy is the requirement for quick resupply in substantial amounts. The primary means in meeting this demand will be strategic airlift (Ref 7:103).

Using strategic airlift resources for this mission (i.e., the resupply of Europe) will not be without complications. For this strategy to work, military planners

NORTHERN AND CENTRAL EUROPE FORCES

	NATO	WARSAW PACT
Main Battle Tanks	7,000	20,500
Tactical Aircraft	2,350	4,200
Artillery (all types)	2,700	10,000
Ground Forces Available in peacetime (division equivalents)	27	47
Combat Manpower	626,000	943,000

Fig. 1. European Force Comparisons (Ref 24:15-28)

must know the capability of the strategic airlift system and
the constraints of the system.

Problem Statement

The problem in analyzing the strategic airlift sys-
tem lies in developing a method of measuring system capa-
bility. Within this context, the goal of this thesis is to
portray the strategic airlift system and identify the
critical factors which affect its operation. Additionally,
a by-product of this effort will be the ability to forecast
an upper limit of the amount of cargo delivered in any
given period of time. The importance of these goals cannot
be overstated.

A concept which relates to these goals is the con-
cept of force readiness. A broad definition of readiness
is the ability of a force to accomplish a given mission

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(Ref 23:2-4); naturally, different missions will require different measures of readiness. In the mission of strategic airlift, cargo moving capability in terms of tons moved within a certain time period is very appropriate. Other measures of aircraft readiness include average aircraft flying time per day (UTE rate), aircraft maintenance ground time, and a myriad of other measures which indicate the efficiency of individual functions associated with strategic airlift. And, as with any large system, improvement in the individual functions (or subsystems) should result in improvement of the system as a whole. Additionally, the system may prove to be more sensitive to changes in one subsystem than another. Ultimately, all subsystems affect the single most important readiness measure in strategic airlift: the amount of cargo moved. By determining how the individual subsystems affect cargo-moving capability, a positive statement can be made on what actions should be taken to increase the readiness level of U.S. strategic airlift.

Overview

The remaining chapters parallel the research design employed in conducting this thesis. Chapter II discusses the airlift system as it currently exists. Once this system was thoroughly researched, assumptions and limitations were applied to the system in order to build a computer simulation model. After the model was constructed, the

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input parameters, structure, and output were validated and all computer operations were verified (see Chapter III). Once validated and verified, the model was used to conduct experiments and test selected system factors for their impact on system operation. This aspect of the system is covered in Chapter IV. Finally, the results from these experiments lead to conclusions and recommendations in Chapter V.

II. System Description

Introduction

The MAC strategic airlift system is a large, complex structure. An overall view reveals that the airlift system can be broken down into several subsystems. If the functions of these subsystems, their interactions, and their effect on system capability can be understood, then a model of the system can be developed to simulate system operation. This chapter describes the airlift subsystems, their effect on system capability, and the model that was developed to simulate the airlift system.

The Airlift System

The MAC strategic airlift system can be represented in several different ways. At a very basic level, it can be represented as an input-output system as shown in Figure 2.

The dotted line showing the boundary of the MAC system indicates that some parts of the input and output are external to the airlift system. This suggests that the airlift system does not operate in a vacuum but is related to other systems. External inputs consist of things like directed requirements, cargo to be moved, or desired capability. Inputs within the MAC system are aircraft available, operating bases, spare parts, personnel, fuel, etc.
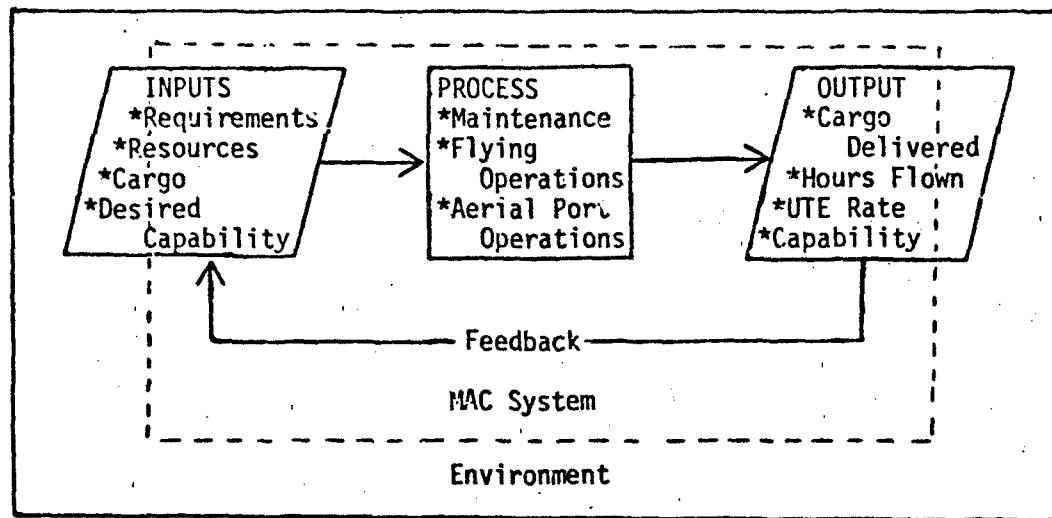
Fig. 2.   Input-Output Model of MAC System

The process of using these inputs to reach the desired output includes flying the aircraft on assigned missions, maintenance to fix the aircraft or keep them operating, and aerial port operations to handle the cargo. The outputs of the system are hours flown, cargo delivered, or some other measure of system capability. The feedback loop compares the output with the input to see if the desired capability has been met or the cargo has been moved.

Figure 3 uses a causal loop diagram to expand the view of the airlift system and show the interrelationships between the elements within the system. In this diagram, a positive sign (+) indicates a direct relationship between the two connected components; i.e., an increase in one results in an increase in the other. A negative sign (-)
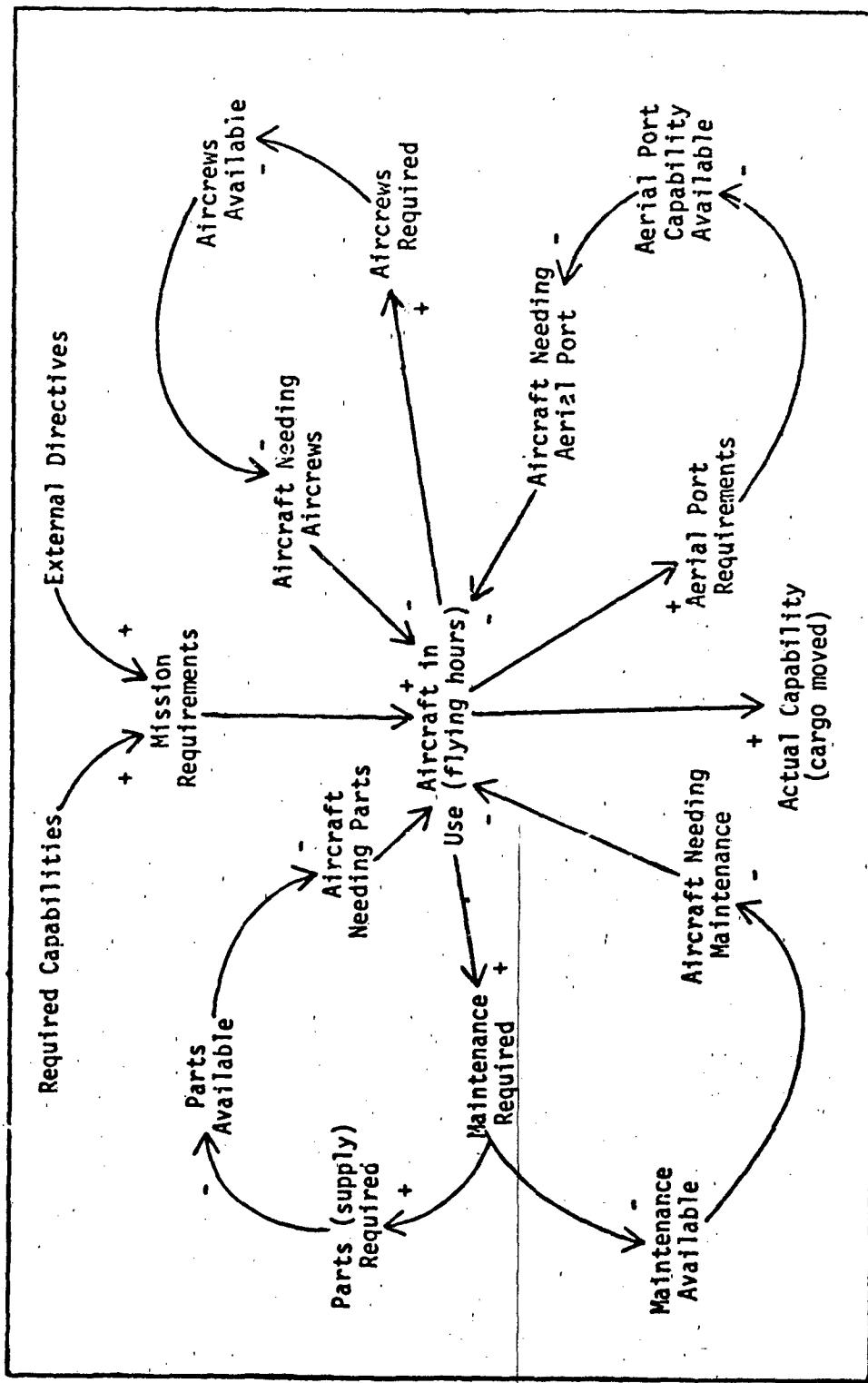
Fig. 3. Causal Loop Diagram of MAC System

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indicates an inverse relationship; an increase in one results in a decrease in the other (Ref 22:13).

This view of the system still indicates that desired capability (i.e., cargo moved) is the input to the system and that actual capability is the output. Figure 3 also shows that the system itself is composed of four main subsystems: aircrews, maintenance, supply, and aerial port. Each of these parts will be discussed in terms of how they operate within the system.

Subsystems

Aircrews. As each required mission is generated, a particular aircrew is assigned against that mission. Since crewmembers can be interchanged between squadrons or wings to meet mission requirements, it is possible on a large scale to view all available aircrews as one resource pool. Approximately two hours prior to the scheduled departure time of the mission, the aircrew arrives to perform the flight planning and preflight. This arrival time marks the beginning of the duty day for the aircrew. Once all preflight activities have been completed, the aircrew and aircraft depart on the mission. The crew may fly one or more missions legs during a duty day as long as the estimated landing time for a particular leg does not exceed sixteen hours from when their duty day started.

When the aircrew has completed their flying for a particular duty day, they are given crew rest time as

specified in the appropriate MAC 51-XX series regulations.
This crew rest time is a minimum of 12 hours from when all
postflight duties are complete. At the end of crew rest,
the crew is again available to fly a mission. This cycle
continues until the crew returns to its home base. At that
time the crew is normally given an extended amount of crew
rest which is based on the time spent away from home. During a contingency, however, this extended crew rest may be
waived and the minimum 12 hours crew rest applied.

Maintenance. The second major subsystem of the airlift system is maintenance. Maintenance is responsible for
the aircraft themselves. This includes repairing broken
aircraft and assigning aircraft for each mission. At
enroute stops, the amount of maintenance performed is dependent upon the length of time the aircraft is planned to be
on the ground and the severity of any problem encountered.
If it is desired to keep the ground time to a minimum, only
those items required for safety of flight or by regulation
will be repaired. All other maintenance will be deferred
until the aircraft is scheduled for a longer ground time
or returns home.

When an aircraft returns to its home base, generally all of the maintenance discrepancies will be cleared.
However, this may be modified by the availability of other
aircraft to perform the required missions. In other words,
if other aircraft are available, then all maintenance items

can be repaired. However, if the aircraft is needed for another mission, then, again, only the essential items will be fixed.

The rate at which maintenance people can repair aircraft is related to the availability of qualified personnel. Generally, if more maintenance personnel are available, then an aircraft can be repaired more quickly or more aircraft can be repaired at the same time. Since some sort of shift schedule is necessary, only a portion of the total maintenance force is available at any one time and this places a limit on the rate of aircraft repair.

Supply. Supply is another major subsystem of the airlift system and is directly related to maintenance since the ability of maintenance to repair the aircraft is dependent on the supply of spare parts. Generally, a stock of those parts most frequently needed will be maintained within the local base supply system. For those items which are out of stock, replacement parts must be ordered; the time it takes for these parts to arrive affects the rate at which maintenance can produce aircraft that are ready to fly.

Aerial Port. The final subsystem of the airlift system shown in Figure 3 is aerial port. Aerial port is that part of the system that has responsibility for all the cargo handling. The aerial port receives the cargo from the shipper, documents and processes the cargo for transport, loads and unloads the aircraft, breaks down the cargo

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loads, and insures receipt of the cargo by the user. As
with the maintenance subsystem, the rate at which cargo can
be moved through the airlift system is dependent on the
number of qualified personnel available. Generally, the
more aerial port personnel available, the faster cargo can
be processed and moved through the system. In peacetime,
movement of cargo through the airlift system is considered
only a secondary benefit to the primary objective of train-
ing (Ref 1:1). However, this cargo movement provides
valuable training for the aerial port personnel who will be
an important part of the system in any wartime scenario
requiring the rapid movement by air of men and material
from one location to another.

As shown in Figure 3, all parts of the airlift sys-
tem must function in order for the system to continue opera-
tion. One problem associated with this system is deter-
mining the proper level each subsystem should be exercised
at in order to produce the desired output. Several
approaches have been made in an attempt to model the air-
lift system and in some way relate the output capability of
the subsystems to overall system capability.

Historical Approaches

Historically, MAC has viewed each of the major com-
ponents of the airlift system separately. Although all com-
ponents of the system were considered important, the air-
crews were agreed to be the part that determined system

capability (Ref 27). This approach expressed the required system capability in terms of a required aircraft utilization (UTE) rate. The necessary day-to-day flying needed for the aircrews to be able to achieve the required UTE rate was then determined. The idea was that if the system was exercised sufficiently for the aircrews to achieve the required system capability, then the other parts of the system would automatically receive enough use to support this requirement (Ref 29). This approach is shown conceptually in Figure 4.

Required system
capabilities

↓

Required aircraft
UTE rate

Needed. flying
hours for

Aircrews -
Maintenance -
Supply -
Aerial Port -
to support
required UTE rate

Largest # flying
hours needed =
minimum flying
hours required
for system to
meet requirements
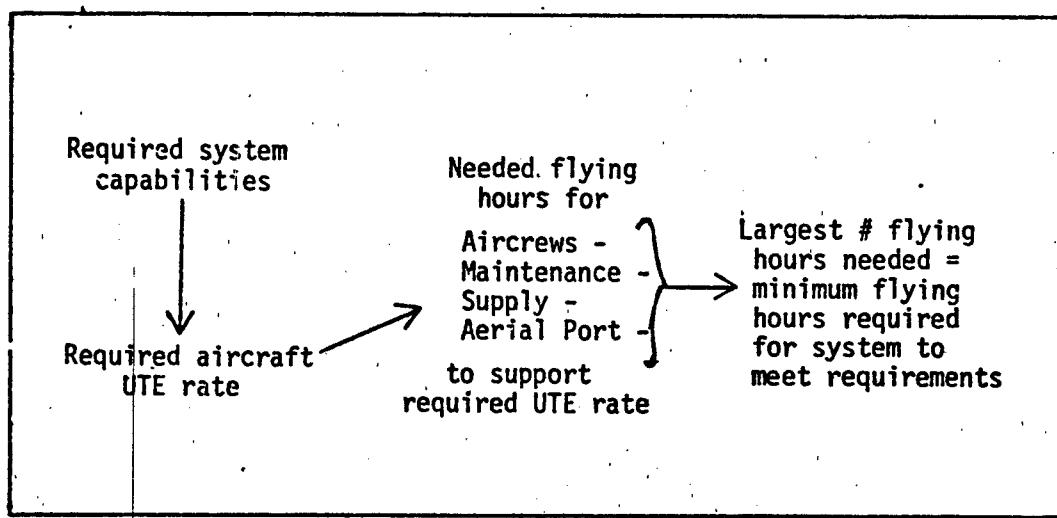
Fig. 4. Historical View of MAC System

In 1977, the capability of the airlift system was carefully reconsidered and a new approach to system capability was developed: it was now believed that the aircrews might not be the driving factor of system capability in all cases. The new approach was to consider each major

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element of the system and then determine the amount of exercise required by the system for that element to achieve its required capability. Again, the required capability was expressed as a required UTE rate. Each major element of the system was studied to determine how it related to the flying hours or UTE rate, and what peacetime flying was needed in order for that element to support the required wartime capability. However, this approach assumed that the subsystems were independent so each subsystem could be considered in isolation. This view of the airlift system is shown conceptually in Figure 5.
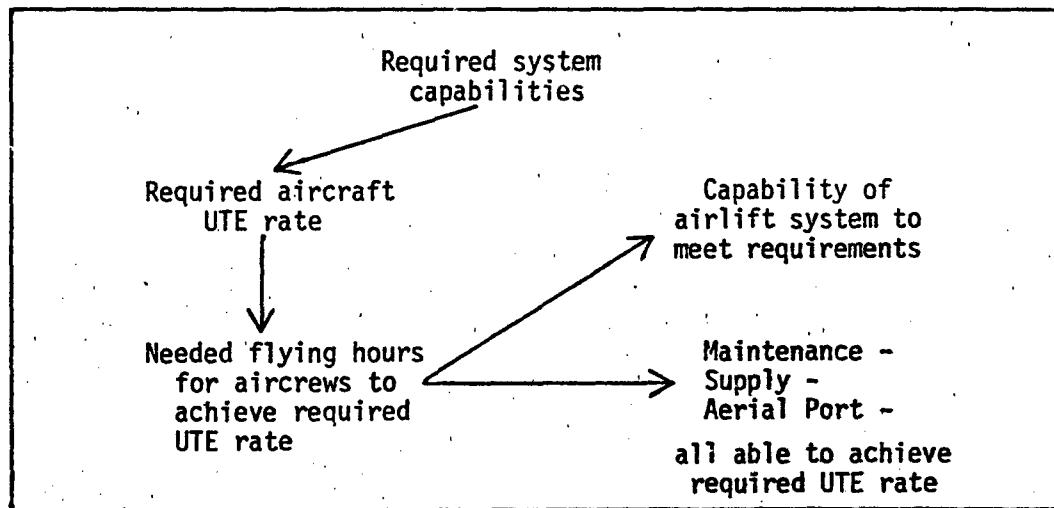
Fig. 5. Revised View of MAC System

It has been suggested (Ref 12) that the above approaches are insufficient to capture the dynamics of the interactions between elements of the airlift system; what is needed is a large scale simulation. Such a simulation

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would take into account the individual situation at each base and hence be responsive to transient shortages of any element at a base rather than looking at each component in an aggregated manner for the whole system. In other words, the base level detail is necessary to obtain a realistic measure of the true capability of the system (Ref 12:36). The Operations Research Division at MAC has taken just this approach. They have attempted to model the entire air-lift system on a base-by-base level (Ref 17). The result has been over three years of effort and a model so large and complex that it is not yet validated and consequently is not useable as an indicator of airlift system capability.

This thesis suggests an alternate approach to the problem of airlift system capability. Instead of starting from the required capabilities and determining what is needed to meet those capabilities, the airlift system is modeled as it presently exists. The resulting current capability of the system is then one of the outputs of the model. This approach incorporates the same four subsystems of aircrews, maintenance, supply, and aerial port as have been considered previously. However, they are now con-sidered as a whole system rather than as independent parts. This allows for the possibility of interaction between the different parts of the system. An aggregated base concept is used to avoid the unwieldy product that results from including many bases in detail. Although some of the

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accuracy may be lost, the result is a workable size model that provides a first order indication of airlift system capability.

Assumptions and Limitations

The scenario used as a basis for structuring the airlift system model is the outbreak of a major war in Europe. This war requires a rapid, large scale airlift of equipment and material to Europe to support the fighting. However, this outbreak of fighting is not a complete surprise as tensions had been rapidly building for several days. Using this scenario as a reference, several assumptions are made that affect both the model's view of the system and the model starting conditions. These assumptions are outlined below.

The increasing tension and anticipation of the outbreak of fighting allowed MAC to make some preparations for the expected airlift requirements. First, all aircraft missions were cancelled and any aircraft away from its home base was directed to return home as soon as possible. Once the aircraft were home, any necessary maintenance was performed. Because of these actions, all aircraft to be used in this contingency are at their home base and fully operational at the beginning of the simulation. Also, all the aircrews have been put on alert, including some crews prepositioned in Europe, so that they are immediately available.

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The suspicion of an imminent attack has also allowed the Army, in cooperation with MAC aerial port personnel, to prepare some of the material and equipment for airlift. Therefore, there is cargo immediately available and cargo continues to be available. The result of this assumption in terms of the model is that aircraft never wait for cargo; cargo waits for the aircraft. In this way the maximum capability of the airlift system, when cargo availability is not a factor, can be determined.

The simulation model uses an aggregate base in the U.S. and an aggregate base in Europe. Although the airlift system has many bases, the use of aggregate bases permits concentration on overall system operation as opposed to the detailed operation of many bases. Additionally, the MAC airlift system has the capability, if necessary, to mix aircrews from different bases, interchange aircraft assigned to a mission, and rapidly move resources from a base with a surplus to a base with a shortage. Therefore, the concept of aggregated bases simply assumes that any resources can be moved quickly enough for the U.S. and European theaters to be viewed as single entities instead of groups of individual bases.

In the system, an aircrew may often fly several short legs or a short and a long leg (e.g., Charleston to Dover and Dover to Ramstein) during one duty day. However, since aggregate bases are used, the only legs specified are

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the U.S. to Europe and Europe to U.S. legs. Because of the length of these legs and the necessary ground times, it is not possible for an aircrew to make a round trip flight in one duty day. Given this situation in the model, all aircrews are automatically given crew rest upon landing.

Due to the large number of aircraft arriving and the limited ramp space, the ground time in Europe of each aircraft is kept to the absolute minimum with all but the most essential maintenance being deferred until the aircraft returns to the U.S. Within the model, it is assumed that only some minor preflight maintenance may be required in Europe. Within the stated scenario it is entirely possible that most rules on what aircraft systems are required will be significantly altered, especially with an empty aircraft on a return flight to the U.S. For this reason, it is not unreasonable to assume that only minor maintenance will be performed in Europe. Also, since the primary output of the model is tons of cargo delivered to Europe, it makes no difference whether the time that an aircraft is down for maintenance is divided between Europe and the U.S. or whether all of the maintenance time is calculated at the end of the Europe to U.S. flight. Because of the high priority of the missions it is assumed that once an aircraft is airborne, it will continue on to its destination. Therefore, the possibility of an enroute abort is not included in the model.

As with any model, there are limitations on the use of the model because of the purpose for which it was constructed. This model is not specifically designed to give an accurate value to the capability of the airlift system, but rather to investigate the relationships within the system. Thus, the output is primarily used as a means of comparison between different runs of the model. In this way, the output provides a relative comparison of different effects on the capability of the system.

Model Structure

Before modeling a system in any given computer language, the specific issues contained within the system must be identified. Once the resultant generic description of the system is established, work can begin on fitting an appropriate simulation language to the system. In the case of strategic airlift, specific issues are addressed by three functional areas (cargo, aircrews, and aircraft) which employ the four previously defined main subsystems of aircrew, maintenance, supply, and aerial port (see Figure 6). The questions raised by these functional areas are presented in Figure 7, 8, and 9. Note that the questions raised by each functional area are more concerned with the output of the subsystems employed rather than the detailed inner workings of the subsystems.

Besides the airlift system itself, the three structures in Figure 7, 8, and 9 share a common link in the type

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SUBSYSTEMS: FUNCTIONAL AREAS:

AIRCREWS   AIRCREW

AERIAL PORT   CARGO

SUPPLY   AIRCRAFT

MAINTENANCE
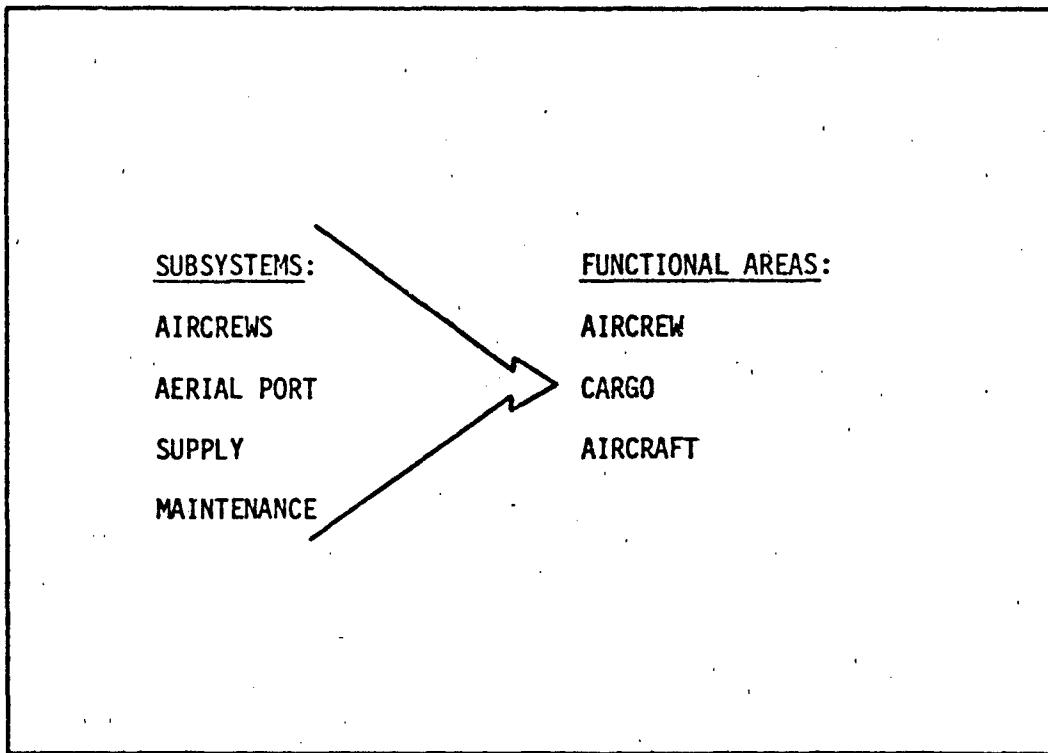
Fig. 6.   Functional Areas and Subsystems
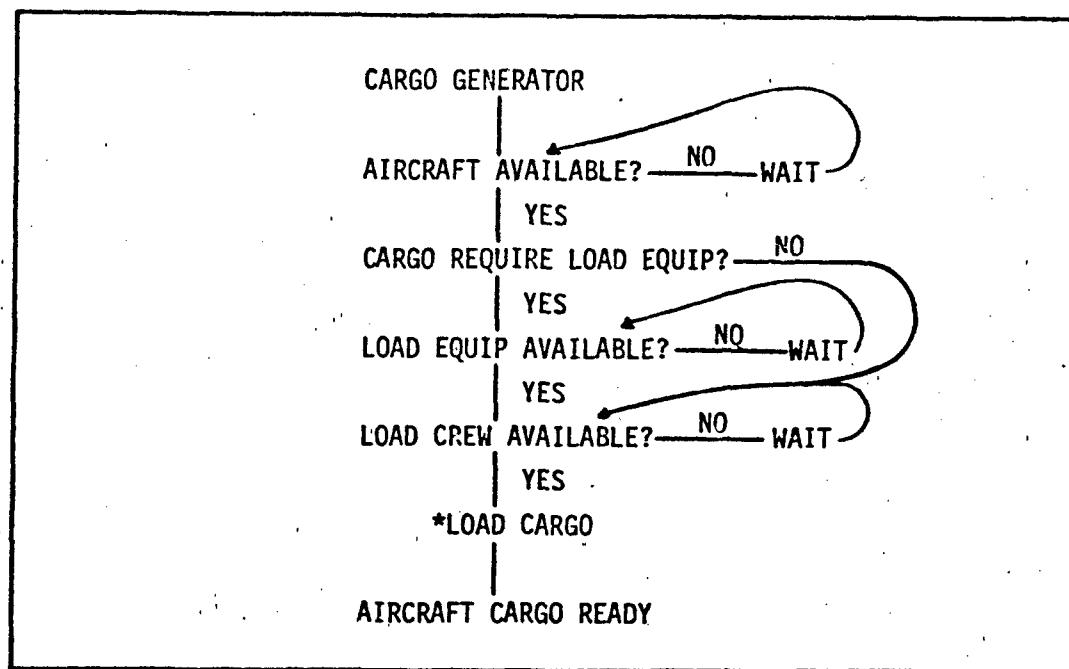
Fig. 7. Cargo Logic Structure
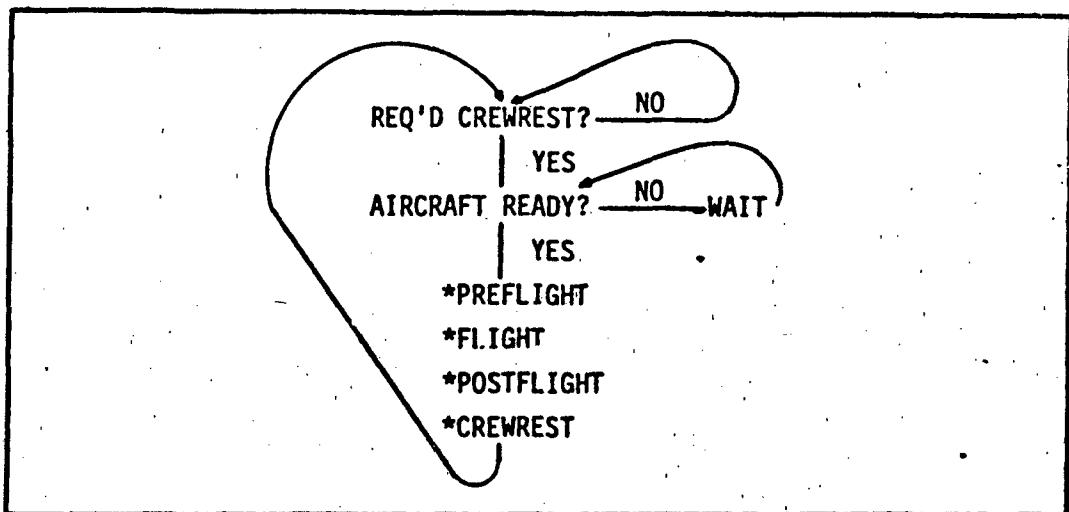
Fig. 8. Aircrew Logic Structure
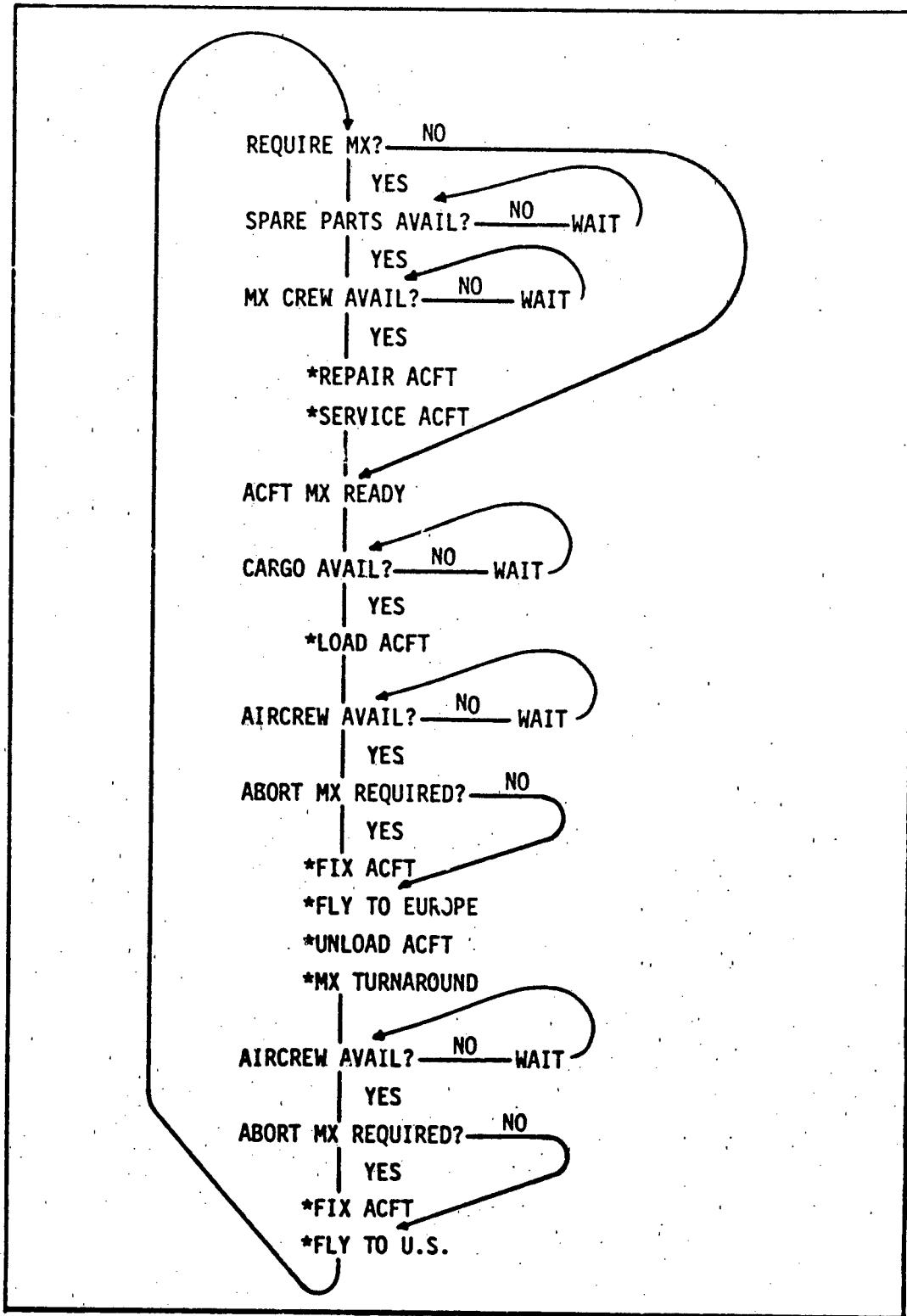
Figure 9. Aircraft Logic Structure

of questions asked and responses required; they all wait
for resources, employ them, then release them. Further,
it may be deduced that employment lasts for a specified
amount of time. This type of system is well suited for a
network simulation language. Additionally, the simulation
language chosen must be flexible enough to allow manipula-
tion within the three functional areas. SLAM (Simulation
Language for Alternative Modeling) is such a language and
is used in this modeling effort.

The SLAM Model

The SLAM program was constructed in three segments
which were later combined to form this single program.
Each segment represents a particular phase in the U.S.-
Europe airlift system. Segment one (lines 4250 through
4810) represents the loading of cargo bound for Europe.
Segment two (lines 4820 through 5340) matches aircrews with
loaded airplanes and flies them to Europe. There, aircraft
are unloaded and aircrews are put into crewrest. The final
segment (lines 5350 through 6430) portrays aircraft turn-
around in Europe and return to the U.S. Once in the U.S.,
aircraft go through maintenance (if required) and then
re-enter the system at segment one. In the remainder of
this section, each segment will be presented in detail.
The entire computer code is available for referencing in
Appendix A. The SLAM network structure is presented in
Figure 24 in the appendix.

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Segment One: Cargo Loading. In segment one, the
cargo is the focal point of the system. The first step
calls for cargo creation. In this system, cargo availability is not considered a factor. For this reason, there is
no constraint placed on how fast or when cargo is created
(see line 4280). However, a six-minute time interval
between creations is specified in the system. This is to
keep the simulation time clock advancing at a reasonable
pace and also to keep the system from being flooded with
"waves" of simultaneous takeoffs from the U.S. Another
apparent constraint on cargo creation is the condition in
lines 4290 and 4300. These conditions effectively turn off
the cargo generator when all aircraft are being used, thus
preventing an overabundance of non-moving cargo entities in
the system which would otherwise require a large amount of
computer memory. Therefore, the conditions specified are a
machine limitation, not a system limitation.

Each release from the create node sends a cargo
entity to a C-141 stream and a C-5 stream. In each stream
the cargo waits for an aircraft resource and is marked in
attribute two to identify the cargo as being C-141 cargo
(atrib(2)=1, line 4320) or C-5 cargo (atrib(2)=2, line
4430). Further, the cargo is identified as either requiring
load equipment and load personnel (atrib(3)=.1, lines 4410
and 4510), or load personnel only (atrib(3)=0, lines 4390
and 4530). The percentages of cargo requiring load

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equpment (i.e., 41.4 percent for C-141s and 65.2 percent for C-5s) were calculated from data used by MACRO-14 (Ref 17). The time it takes to load the cargo is assigned to attribute four and is also taken from MACRO-14 data. Once the cargo is marked, it waits for either load equipment (line 4580) or load personnel (line 4630) as appropriate. When these requirements are met, the cargo is loaded onto the aircraft (line 4690) and the load equipment and personnel are freed for other jobs (lines 4730 and 4750). At this point, statistics are collected which reveal how long it took the cargo to get from the "loading dock" (create node) to the airplane. Now, the only thing keeping the cargo on the ground is lack of an aircrew to fly the aircraft.

Segment Two: The Aircrews. Immediately after the aircraft are loaded, they wait for aircrews to become available (C-141s at line 4850, C-5s at line 4900). All aircraft then follow the same routine in their flight to Europe. First, attribute five is marked with the time the aircrew came on duty so that crew duty day statistics may be collected. Then the aircraft go through a delay for preflight and taxi to the runway (line 4970). Before takeoff, 15 percent of the aircraft will experience some sort of maintenance difficulty and require pre-takeoff maintenance (line 5040). This percentage is derived from information contained in reference 18. After pre-takeoff maintenance

is accomplished, the aircraft is assigned its flight time from a normal distribution with a mean of 7.7 hours (line 5090). Variation in flight time is provided to account for varying winds and destinations in Europe. After landing in Europe, the aircrews are separated from the aircraft (lines 5230 and 5240), and go through postflight activity which lasts between one and one-and-a-half hours. Following postflight activity, statistics are collected on crew duty day and the crews are put into 12 hours of crew rest before being made available for return flights to the U.S. (lines 5230 and 5330).

Segment Three: The Aircraft. This segment starts at line 5380 where the aircraft routine after landing in Europe begins. Here, the procedure is to first wait for load equipment or personnel as required (recall that the cargo was marked in attribute three earlier). When these requirements are met, the cargo is unloaded (line 5440); unloading time is based on the exact type of cargo being unloaded (that is, bulk, oversize, or outside cargo). This determination is made in user function two and is derived from reference 17. After unloading is accomplished, statistics are collected on the total transit time of the cargo and the total weight (in tons) of the cargo moved (line 5510).

For the return flight to the U.S., C-141s are separated from the C-5s, though both aircraft follow

similar routines. First, the aircraft go through maintenance postflight, refueling, and preflight (lines 5620 and 5900). Because these return flights are not critical cargo carriers, it is assumed that any maintenance required can wait until the aircraft return to the U.S. Therefore, no maintenance is scheduled to take place in Europe for this model. The next step, then, is for the aircraft to wait for an aircrew to become available (lines 5660 and 5940). Again, time is allocated for aircrew preflight and taxi. Also, 15 percent of the C-141s and 30 percent of the C-5s require pre-takeoff maintenance and will incur a delay on the ground (lines 5700 and 5980). After this delay, aircraft fly to the U.S. where the aircrews are placed in crew-rest and subsequently are released for duty (lines 5840 and 6120). The aircraft go through quite a different routine than the one followed in Europe.

Aircraft are given a 50 percent chance of requiring maintenance actions (line 6190). When an aircraft enters the maintenance stream in the system, it is assigned attributes which record the time it is to spend in maintenance (line 6210), the number of items which required maintenance (and, hence, the number of maintenance crews employed) at line 6230, and, finally, the time delay due to supply (line 6250). These values are calculated in events one, two, and three respectively. After the aircraft is fixed, it goes through a turnaround phase at which time is is refueled and

preflighted by maintenance (lines 6350 and 6360). The turnaround time is determined in user functions four and five. With this done, the aircraft is released to its respective resource block and is made available for another mission to Europe (lines 6400 and 6420). At this point, the cycle starts again at segment one.

In addition to the network statistics already discussed, this model also allows manipulation of key variables on a daily basis in event four. Within event four, such things as daily UTE rate and total tonnage delivered are made available for analysis.

Summary

This chapter initially presented an overall view of the MAC airlift system and described the four main subsystems of aircrews, maintenance, supply, and aerial port. Several previous approaches in employing these subsystems and determining system capability were presented. Noting the deficiencies in these approaches, an alternative, holistic systems approach using computer simulation was presented. Assumptions and limitations were then applied to the system and the subsequent development of a computer model was described.

However, the development of a computer model is not sufficient by itself. The validity of the model must be established for the model output to be useful for

analysis. Chapter III describes the validation and verification cation process accomplished.

III. Validation and Verification

Introduction

The acceptance of any model as a useful tool depends largely on the user's confidence in the model structure and output. Building this confidence can be achieved on two planes. The first plane is model validation. There are several aspects of validation which can be employed. Thus far, emphasis has been placed on the design validity of the model structure as presented in Chapter II. To further confidence in the model, the input parameters and model output must also be validated. Because there is no actual data available on this scenario (i.e., the wartime resupply of Europe), rigorous validation of the output is not possible and will, therefore, be limited in scope. The second plane of confidence deals with the verification that the model indeed operates as it was intended. Verification entails checking for correct mathematical operation and proper computer logic within the computer code.

Input Validation

Many different pieces of data were gathered to help build a realistic portrayal of the strategic airlift system. The purpose of this section is to present the methods used in collecting this descriptive data and reducing it to a useable format for the computer model. Most data was

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provided by Headquarters, MAC, although other sources were
also used. The bulk of the data is concerned with four
areas: aircraft maintenance, supply delay time, aircraft
loading and unloading times, and cargo weight per aircraft.
Though other parameters in the model did not require much
data reduction, they are discussed in the final segment of
this section.

Aircraft Maintenance. The amount of time an air-
craft spends in maintenance is a function of how often it
breaks (i.e., is declared Non-Mission-Capable-for-
Maintenance), how many items require repair once the air-
craft is declared NMCM, and how quickly maintenance per-
sonnel can repair the aircraft. The supply of replacement
parts is also a factor, but will be discussed separately.

It is important to separate wartime maintenance
from peacetime maintenance for a number of reasons. First,
the scenario for this model is contingent upon an outbreak
of war in Europe. In such a setting, some maintenance
items can be overlooked (such as an inoperative instrument
in the co-pilot's position), while some cannot (such as an
inoperative electrical system). Because of this reduction
in required maintenance, peacetime maintenance data cannot
directly reflect wartime maintenance requirements. What is
needed, then, is data which reflects maintenance require-
ments of wartime essential subsystems. Data of this nature
is very difficult to obtain, however, as no direct

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reporting system exists for wartime maintenance. Therefore, peacetime data which covered stateside maintenance over a three-month period was obtained on ten different C-5s from Headquarters, MAC. From these computer listings, maintenance accomplished on minimum essential subsystems as contained on the MAC Minimum Essential Subsystems List (Ref 3) was extracted. The specific data included the number of broken subsystems per aircraft visit to maintenance and the amount of time the aircraft spent in maintenance. From this collection, 139 data points were plotted in four-hour groups (see Figure 10). Though the reporting system does not indicate delay due to supply, 14 data points (representing 10 percent of the total data) were discarded because their high time in maintenance (i.e., over 36 hours) was probably due to supply delays. In some cases, this assumption was fairly obvious: one data point indicated a C-5 in maintenance for ten days. For other cases, however, the 36-hour cutoff point represents an approximate estimation of maximum time for maintenance based on experience and interviews with maintenance personnel. Once this data was plotted, the resultant cumulative histogram was connected by linear lines with break points at 3, 6, 18 and 26 hours. The endpoints are at the minimum observed time in the maintenance data at one hour and the maximum time allowed at 36 hours. This set of linear lines is the basis of

MX HRS	0	4	8	12	16	20	24	28	32	36 +	
COUNT	58	20	6	5	7	12	9	5	3	14	139
% TOTAL	41.7	14.4	4.3	3.6	5.0	8.6	6.5	3.6	2.2	10.1	100%
% ADJ	46.6	16.0	4.8	4.0	5.6	9.6	7.2	4.0	2.4	--	100%
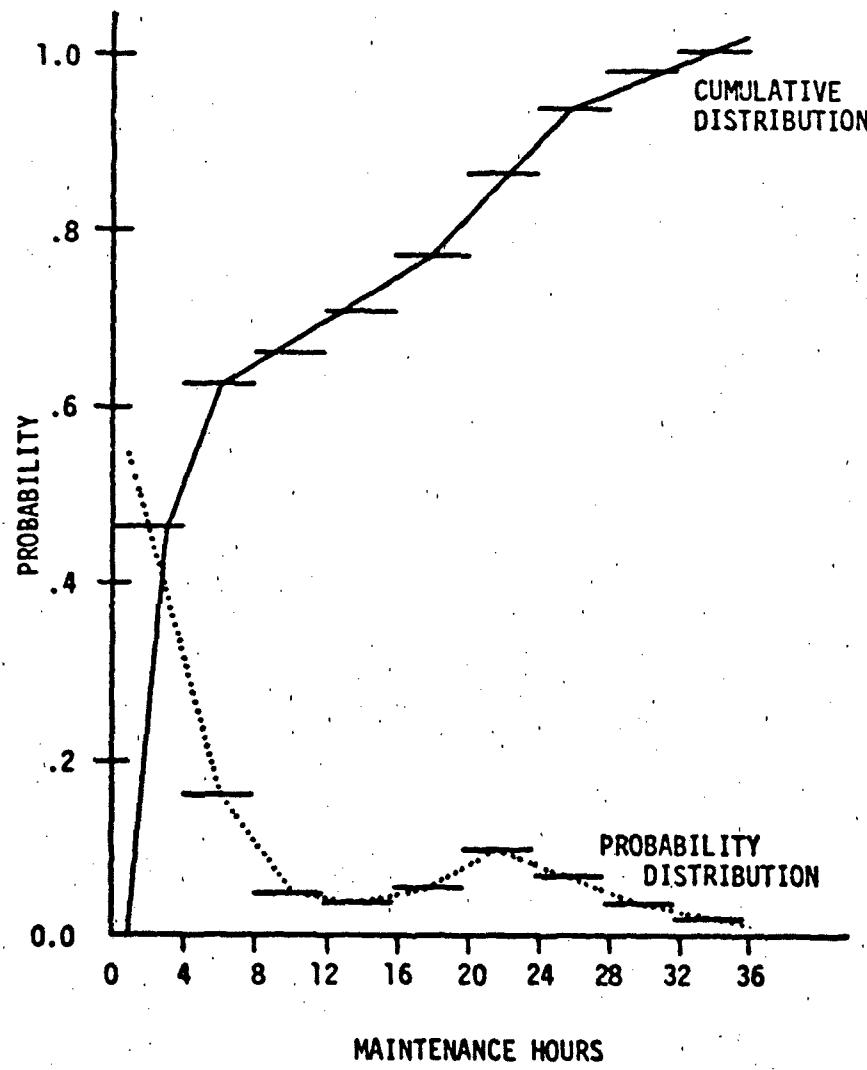
Fig. 10. Maintenance Time Distribution

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determining the time spent in maintenance by aircraft. The computer code is listed in lines 380 and 560.

Related to the time spent in maintenance is the number of maintenance crews required to fix an aircraft. This was determined by plotting the number of maintenance items repaired per aircraft sent to maintenance (see Figure 11). As with the "time in maintenance" data, some data points were disregarded due to their infrequency. Because the number of maintenance items is an integer, the resultant distribution remains in a discrete form. The computer listing for this segment is found in lines 590 through 920.

As mentioned earlier, this maintenance data was extracted only from the C-5 reporting system, as the C-141 maintenance reporting system does not include data of this nature. Rather than simply "making up" C-141 data, several arguments can be made for applying the C-5 data directly to the C-141. First, the aircraft are very similar operationally; they share the same mission, environment, and will be used at approximately the same rate in terms of flying hours per aircraft. Second, both aircraft require similar maintenance as specified in the MESL (Ref 3); in comparing the C-5 and C-141 MESL, many of the categories of subsystems are common to both lists. Finally, the aircraft are historically similar in terms of Not Mission Capable Due to Maintenance (NMCM) rates. In 1980, the C-5 averaged

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# MX ITEMS	1	2	3	4	5	6	7	8	9	10	+	
COUNT	70	16	7	11	5	4	2	2	1	1	20	139
% TOTAL	50.4	11.6	5.0	7.9	3.6	2.9	1.4	1.4	.7	.7	14.4	100%
% ADJ	58.8	13.5	5.9	9.2	4.2	3.4	1.7	1.7	.8	.8	--	100%
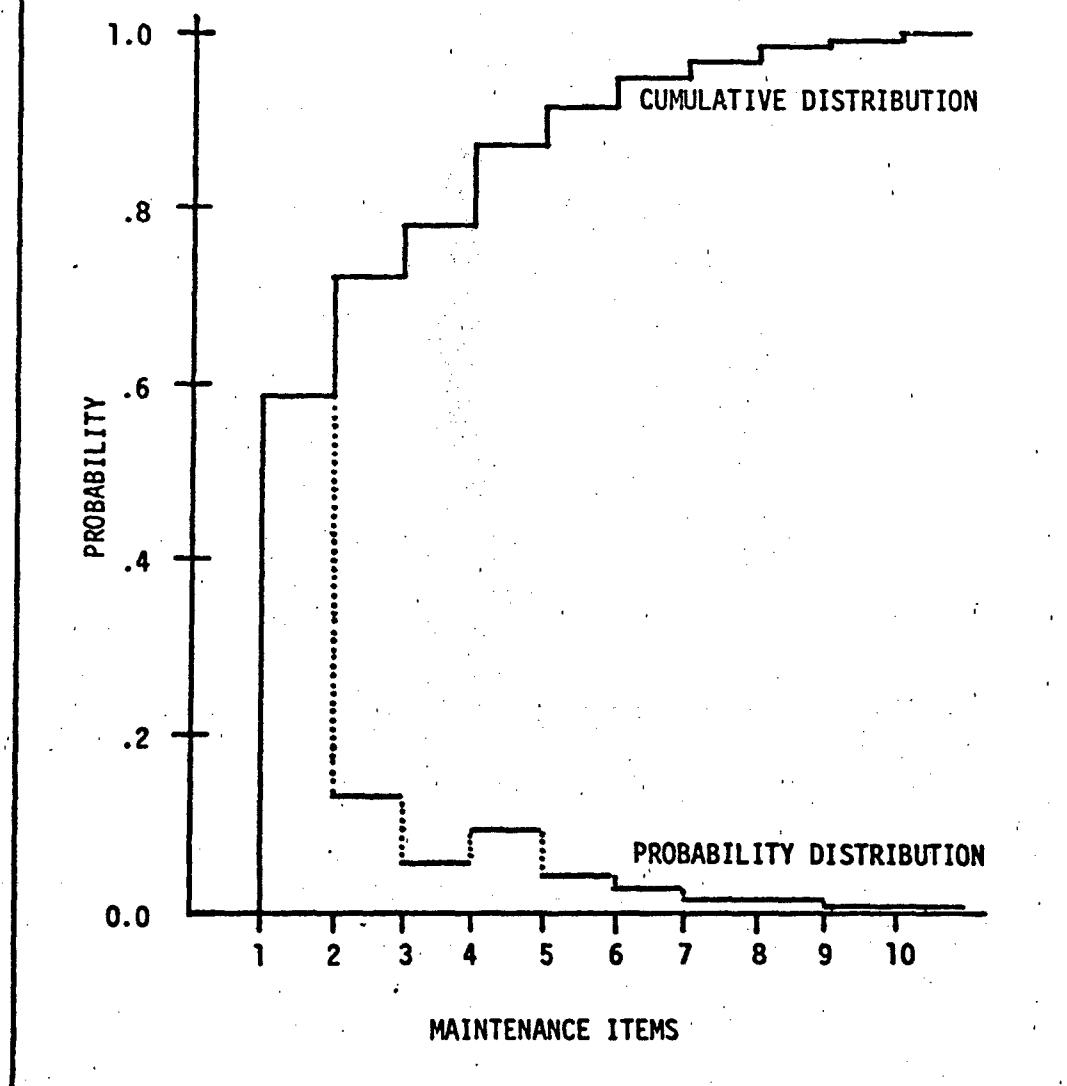
Fig. 11. Maintenance Items Distribution

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a 27 percent NMCM rate and the C-141 had a 22 percent NMCM rate. Because of this parallel nature of the C-5 and C-141 maintenance structure, the model applies the C-5 data to both aircraft. The code for this data is contained in events one and two, lines 380 through 920.

Supply Delay. Supply is an integral part of maintenance; without spare parts, many maintenance functions would grind to a halt. Therefore, the effect of supply must be taken into account. Although the supply system itself is fairly complex, its output (from a user's point of view) is simple. Basically, maintenance people are concerned with two factors of supply; first, when will supply levels reach zero; and second, how long will it take for unavailable spare parts to become available.

The first factor of determining when supply levels will reach zero is a difficult question to answer. Presently, supply levels vary based on demand and resupply rates. However, in the event of war, resupply would be severely curtailed until higher priority cargo (i.e., war materiel) is moved. To insure that supply levels aren't depleted too quickly, War Reserve Materiel (WRM) stockpiles are maintained. These stockpiles are not used during peacetime, but are kept on hand to take up the slack when the resupply function slows down. Estimates on how long WRM can effectively take up this slack varies--much depends on the aircraft utilization rate (which drives the maintenance

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demand), and how slowly the resupply system is operating.
The only data currently available on this problem deal
with Non-Mission Capable due to Supply (NMCS) rates. These
rates, of course, are based on peacetime demand and resupply,
so are not useful in estimating a wartime limit. To esti-
mate a reasonable time to zero supply, then, some assump-
tions are made.

The first assumption is that current supply levels
plus WRM will sustain 60 days of peacetime operation.
Second, preliminary runs of the model indicate an approxi-
mate maximum UTE rate of 16 hours per aircraft (C-5 and
C-141). Given that the peacetime UTE rate is 1.8 hours
for the C-5 (Ref 18:OP5) and 3.14 hours for the C-141 (Ref
18:OP4), time to zero supply can be determined:

For the C-5:

60 DAYS X 1.8 PEACE UTE / 16 WAR UTE = 6.75 DAYS

= 126 HOURS

For the C-141:

60 DAYS X 3.19 PEACE UTE / 16 WAR UTE = 12.0 DAYS

= 288 HOURS

These calculations also assume that the resupply rate is
zero until the WRM is depleted.

Rather than allow the disparity between C-5 and
C-141 WRM effective time to exist, it is assumed that logis-
tics planners have recognized the need for more C-5 WRM
due to the artificially low peacetime UTE rate (due to

structural limitations (Ref 27)). Therefore, the WRM depletion time used in the model is 12 days as calculated for the C-141. Once this point is reached, however, the model must start to reflect resupply times.

Resupply time is the second output factor of the supply system which affects maintenance. Peacetime data (Ref 18) for aircraft grounded while waiting for supply in the CONUS yields distribution curves as shown in Figures 12 and 13. These curves will be used in determining aircraft delay while in maintenance due to supply. Of course, not all aircraft in maintenance will go NMCS and a wartime NMCS rate is required for the model. Peacetime NMCS rates are approximately the same for both aircraft at 5 percent (Ref 18:LOG12). Estimating a wartime NMCS rate is difficult, but an approximate figure can be rationalized simply by multiplying the current peacetime rate of 5 percent by the increase in UTE rate. Again, the C-141 UTE rate will be applied to both aircraft:

$$\frac{5\% \text{ PEACE NMCS RATE X 16 WAR UTE}}{3.19 \text{ PEACE UTE}} = 25\% \text{ WAR NMCS RATE}$$

Aircraft Loading and Unloading. All distributions for loading and unloading times were taken from MAC's Resource Optimization Model-14 (MACRO-14). While this data has not been completely validated in MACRO-14, it represents the best data available at this time. Both loading

FIGURE 12. C-141 SUPPLY TIME DISTRIBUTION

C-5 SUPPLY TIME DISTRIBUTION
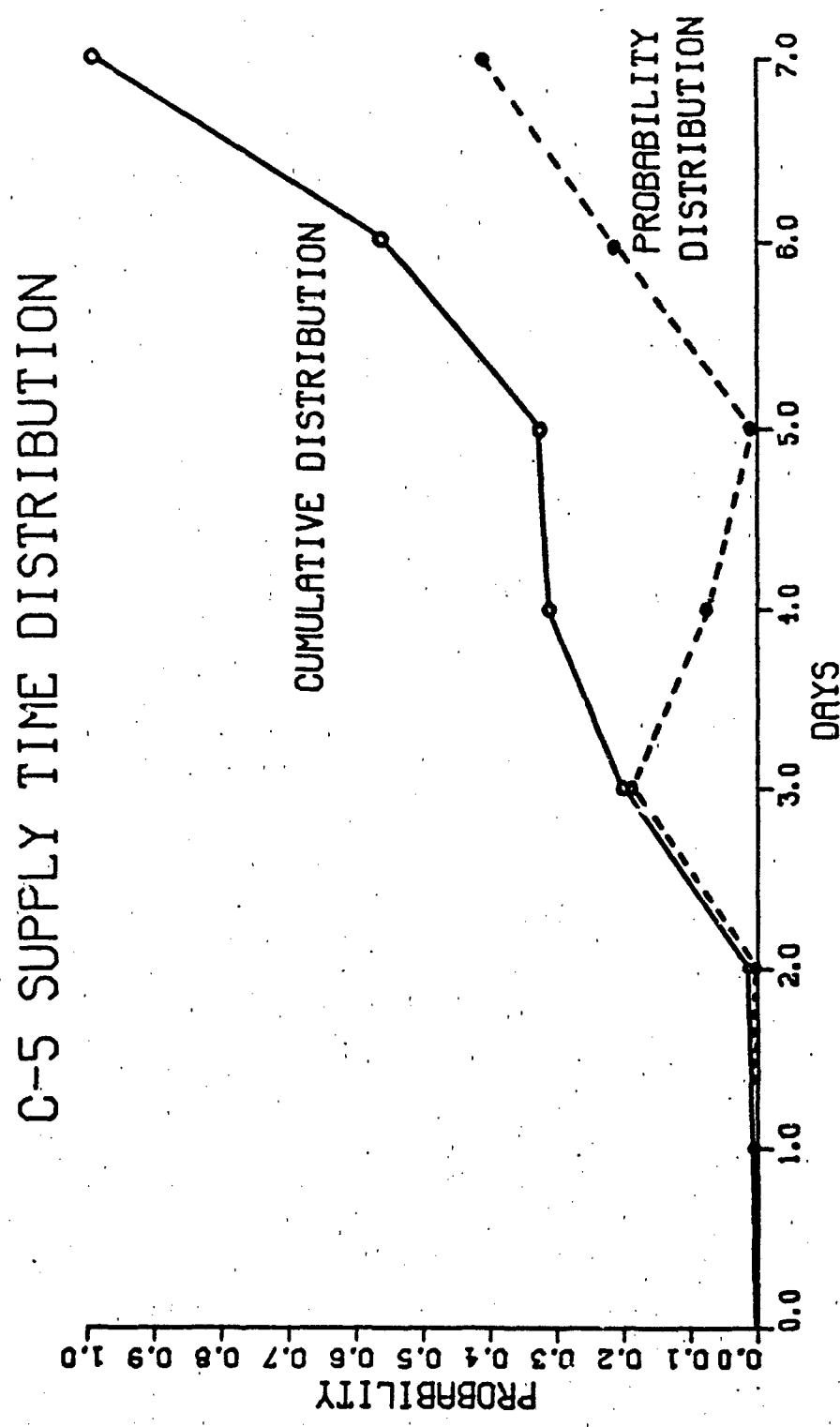
FIGURE 13. C-5 SUPPLY TIME DISTRIBUTION

and unloading times are dependent on cargo category: bulk, oversize, and outsize.

Cargo loading times are not as sensitive to cargo category, so one distribution is sufficient for each aircraft. Cargo unloading times, however, are very sensitive to cargo category (bulk, oversize, and outsize). Before assigning a loading time, then, the type of load must be determined. The C-141 is restricted to only bulk and oversize loads. Data in MACRO-14 indicates that of the total bulk and oversize cargo movement requirement, 26.8 percent is bulk, and 73.2 percent is oversize. For the C-5, 22.5 percent of all cargo is bulk, 61.5 percent is oversize, and 16 percent is outsize. These percentages are reflected in the model at lines 2150 for the C-141 and lines 2260-2270 for the C-5. The time distributions are listed in Table I.

Because load equipment or load crews are employed to handle the cargo, a distinction must be made between cargo that requires both load equipment and load crews (i.e., palletized cargo), or cargo that requires only load crews (i.e., "rolling stock"). For the C-141, 58.6 percent of the cargo loads require load crews only, while the remainder is palletized (see lines 4370-4380). For the C-5, 34.8 percent of the cargo loads require load crews only, with the remainder palletized (see lines 4490-4500). These figures are derived from MACRO-14.

TABLE I.

CARGO HANDLING

CARGO ONLOAD TIME DISTRIBUTIONS

C-141

ALL CARGO:	NORMAL:	MEAN=	1.3 HRS
		STD DEV=	.2 HRS

C-5

ALL CARGO:	NORMAL:	MEAN=	3.5 HRS
		STD DEV=	.6 HRS

CARGO OFFLOAD TIME DISTRIBUTIONS

C-141

BULK CARGO:	NORMAL:	MEAN=	1.0 HRS
		STD DEV=	.2 HRS
OVERSIZE CARGO	NORMAL:	MEAN=	.84 HRS
		STD DEV=	.2 HRS

C-5

BULK CARGO:	NORMAL:	MEAN=	3.0 HRS
		STD DEV=	.5 HRS
OVERSIZE CARGO:	NORMAL:	MEAN=	2.44 HRS
		STD DEV=	.9 HRS
OUTSIZE CARGO:	NORMAL	MEAN=	2.3 HRS
		STD DEV=	.9 HRS

Aircraft Cargo Loads. The tons of cargo an air-
craft carries is dependent on two things: the weight of
the cargo and the physical size of the cargo. Either of
these factors can limit the amount of cargo an aircraft can
handle. For example, a low density load may reach the
space capacity of the cargo bay before the maximum weight
is reached. From a planning point of view (and specifi-
cally in this scenario), the cargo loads of an aircraft
depend on the type of unit being moved. Because the objec-
tive of current U.S. mobility strategy is to double the
size of U.S ground forces in Europe (Ref 7:201), cargo
loads used in the model concentrate on transporting Army
units. There are five types of Army units considered:
armored, mechanized, infantry, airmobile, and airborne.
Additionally, loads for Air Force units are also considered.
Although no priority is given to any unit type, the model
recognizes that there are, for instance, more mechanized
units than armored units. Specifically, of the major active
U.S. Army forces stationed in the CONUS, approximately 21
percent are armored, 33 percent are mechanized, 21 percent
are infantry, 12.5 percent are airmobile and 12.5 percent
are airborne (Ref 15:25). The planned cargo loads for each
type unit (see Table II) is taken from the USAF Airlift
Loading Model (ALM) as described in MACRO-14. Similar load
distributions were combined in the model to facilitate

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TABLE II

PLANNED CARGO LOADS

Unit Type	C-141 Load (Tons)	Freq (%)	C-5 Load (Tons)	Freq (%)
Armored Div	36-40	38.	99.5-102	82.5
	24-36	.5	94.5-99.5	1
	17-24	24.	89.5-94.5	7.
	14-17	.5	14.5-60.5	9.5
	11-14	33.		
	6-11	4.		
Mechanized Div	34-40	39.	99.5-102	82.
	24-34	22.	94.5-99.5	.5
	11-24	35.	89.5-94.5	5.5
	6-11	4.	14.5-60.5	12.
Infantry	36-40	11.	99-102	51.
	34-36	32.5	89-99	9.
	24-34	1.	74-89	2.
	16-24	28.9	36-69	27.5
	14-16	.1	14.5-36	10.4
	11-14	17.		
	6-11	9.5		
Airmobile	36-40	8.	99-102	9.
	34-36	13.	94-99	4.
	24-34	1.	74-94	3.
	19-24	26.	29-69	33.
	14-19	7.	14.5-29	51.
	11-14	22.		
	6-11	10.5		
	2-6	12.5		
Airborne	36-40	8.	94-102	21.
	34-36	12.	64-69	24.
	24-34	1.	44-64	11.
	19-24	37.	14.5-44	44.
	14-19	4.		
	11-14	20.		
	6-11	8.		
	2-6	10.		
Air Force	27-31	12.5	90-102	20.
	25-27	12.5	60-90	60.
	15.5-25	29.	25-60	20.
	13-15.5	25.		
	9-13	21		

computer processing time. The computer coding for planned cargo loads is contained in lines 2390 through 3830.

Abort Rate. According to peacetime operational departure reliability statistics (Ref 18:PF2-1), the C-141 and C-5 have approximately the same home station reliability at approximately 85 percent. This figure is reflected in lines 5000 through 5040. However, at enroute stations, C-141s continue to be 85 percent reliable while C-5s slip to 70 percent reliability. These figures are reflected in lines 5680 through 5710 for the C-141, and lines 5960 through 5990 for the C-5.

Abort Maintenance Time. Abort maintenance time is uniformly distributed between .5 hours and 1.5 hours. This estimate is based on experience.

Aircraft. The number of C-151 and C-5 aircraft in the system was arrived at by multiplying the respective force size by .75; the entire force is not used because some aircraft must be available for ongoing commitments outside the European Theater. For the C-141 force of 234 aircraft, 176 are used in the model. For the C-5 force of 70 aircraft, 53 are used in the model.

Aircrews. The number of aircrews is based on current authorized crew ratios. The C-5 has a crew ratio of 3.25 crews per aircraft and the C-141 has a ratio of 4.0 crews per aircraft (Ref 27:8-14). These ratios include both active duty and associate reserve aircrews. Thus,

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there are 172 C-5 aircrews and 704 C-141 aircrews in the model. To facilitate crew effectiveness, the model initially places half the crews in the U.S. and half in Europe. This effect would be accomplished in reality by assigning more than one crew per European bound aircraft during the early days of the airlift.

Flight Times. Flight times to and from Europe are based on estimates in AFR 76.2 (Ref 4). The critical leg used is the Dover to Ramstein leg at 3535 nautical miles. Average airspeed is 431 knots for the C-5 and 418 knots for the C-141. Average tail wind along the route is 39 knots. Between the two aircraft, then, average ground speed is approximately 460 knots:

$$[(431+418)/2] + 39 = 463.5 \text{ knots}$$

and the average flight time to Europe is approximately 7.7 hours:

$$3535 / 460 = 7.68 \text{ hours.}$$

Variation in winds and aircraft performance is estimated at (.2 hours) squared. This yields a flight time to Europe which is normally distributed with a mean of 7.7 hours and a standard deviation of .2 hours; this is reflected at line 5090.

Flight time from Europe to the U.S. is similarly calculated and can be found on lines 5720 and 6000 as a

normal distribution with a mean of 9.3 hours and a standard deviation of .2 hours.

Load Equipment. The number of loaders (i.e., that equipment which can load pallets onto C-141s and C-5s) is 28 in the U.S. and 28 in Europe. These numbers are estimated.

Load Personnel. The number of load personnel is based on a ratio of 2.5 load crews per loader per 12-hour-work shift. With 28 loaders in the U.S., 70 load crews are available at any given time and 70 load crews are available in Europe.

Load Availability Rate. This rate determines how many loads per hour are available for loading onto an aircraft. Because an assumption in this model is that cargo availability is not a factor, the number of cargo loads transported per hour is ultimately limited by how many aircraft can take off per hour. By using a 12-minute (.2 hours) take off interval and assuming two runways available (representing two staging areas in the real system), the load availability rate becomes:

5(Takeoffs hour/runway) X 1(loads/takeoff)
X 2(runways) = 10 loads/hour or .1 hours/load.

This rate is reflected in the model at line 4280.

Maintenance Personnel. Like load personnel, this number is reduced to the number of crews available. Out of a total of 5085 people assigned to the maintenance function

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(Ref 18:TR22), only approximately 60 percent actually work on the line with the aircraft. The other 40 percent are involved with overhead functions which include supply interface, shop work (such as avionics equipment recycling), and administrative duties. Interviews in the field indicate that of the 60 percent who do work on the line, only half of these people do actual repair work, while the rest are involved with routine maintenance functions (refueling, crew chiefs, fleet service, etc.). By dividing the line repair personnel into 2.5 man teams working 12-hour shifts, the total number of maintenance teams working at any given time is 305.

Turnaround Time. Turnaround time is a combination of postflight, refueling, and preflight times. In Europe, turnaround is estimated to be uniformly distributed between 2.0 and 4.0 hours for both aircraft. This relatively simple estimation reflects the requirement of quick turnaround in Europe and the expectation that most maintenance will take place in the U.S.

In the U.S., turnaround time is different for each aircraft. For the C-141, postflight and preflight are both normally distributed with a mean of .7 hours and a standard deviation of .08 hours; refueling is estimated to be uniform between 1.5 and 2.5 hours (Ref 17:C1). These values are reflected in line 3900 in the model. For the C-5, postflight and preflight are both normally distributed with a

mean of 1.5 hours and a standard deviation of .12 hours and refueling is estimated to be uniform between 2.0 and 4.0 hours (Ref 17:C1). These values are in line 3980 in the model.

Output Validation

Because this model is intended to concentrate on trends within the airlift system, a high degree of accuracy in the numbers the model produces is not required. And, as stated earlier, the model deals with a scenario which has not been encountered, as there is no historical data to compare with data output. However, these facts do not negate the requirement that the model output be reasonable in order for any user to have confidence in conclusions drawn from the model.

Several pieces of model output from the nominal (all factors at presently existing levels) runs were compared with estimations of system capability from other sources. The comparisons were not tested for statistical significance, but were used to judge if the results appeared reasonable, much as a Turing test would do (Ref 26:29). The results of this output validation are listed in Table III. The comparisons indicate that all output data compare favorably with methodologies and sources unrelated to the model with the exception of the C-141 daily Million Ton Miles (MTM) capability. However, the 25.7 percent difference in this case is due to a difference

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TABLE III

OUTPUT VALIDATION

Output Parameter	Regular Run	Antithetic Run	Model Avg	Ref Data	Ref Number	% Difference (Model-Ref/Ref)
C-141 Tons/Day	2717	2547	2632	2431	11	8.3
C-5 Tons/Day	2244	2215	2230	2473	11	-9.8
Tons Delivered (Thousands)	148.8	142.8	145.8	136.8	10	6.6
C-141 MTM	9.6	9.0	9.3	7.4	10	25.7
C-5 MTM	7.9	7.8	7.9	7.6	10	3.7
MNCS (%)	22.5	27.2	24.9	5.0	18	N/A*
NMCM (%)	11.1	10.7	10.9	30.0	18	N/A*

*Peacetime rate used as reference data.

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in the route distance used in computing MTM. If the same route distance were applied to both the model and the reference data, the percent difference in C-141 MTM would be 6.4 percent. Similarly, C-5 MTM would reflect a -9.9 percent difference instead of the 3.4 percent difference shown.

NMCS and NMCM rates are also included in the table, though no estimate was found on wartime rates. The high model NMCS rate reinforces the importance of spare parts supply even with the low NMCM rate produced by the model. The lower model NMCM rate (as compared to the peacetime rate) is justifiable because of the reduced maintenance requirements in the MESL (Ref 3).

Verification

Verification is the process of insuring the model behaves the way the modeler intends (Ref 26:30). This process is accomplished by the use of techniques based on statistical theory and hypothesis testing. In the simulation model in this thesis, the problem of verification is insuring that the various specified distributions are in fact producing the desired distributions. The inherent capability of the SLAM language is an aid in this verification process. The normal SLAM summary report provides data that can be used and the trace option provides the ability to follow entities through the network and check on the distributional values that are being assigned.

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Although many distributions are called in the model, only three different types of distributions are used. These are: stochastic branching, normal, and uniform. To insure that the SLAM program is in fact correctly executing these distribution types, one representative of each type was verified as outlined below.

To test the stochastic branching, the number of C-141 aircraft needing load equipment and load personnel versus the number needing just load personnel was examined. A test concerning proportions using the normal approxima- tion to the binomial was performed as indicated in Figure 14 (Ref 28:261-262).

Data: 3349 aircraft, 1963 need only load personnel
                        1386 need load personnel and equipment

1. H_0: p = .586 (fraction specified in model as needing
                        only load personnel)

2. H_1: p ≠ .586

3. Alpha: α = .05 ⇒ z = 1.96

4. Critical region: Z < -1.96 and Z > 1.96

5. Computations: n = 3349, x = 1963

$$z = \frac{x - np}{\sqrt{npq}} = \frac{1963 - 3349(.586)}{\sqrt{3349(.586)(.414)}} = .017$$

6. Conclusion: z is not in the critical region
                        fail to reject H_0

Fig. 14. Stochastic Verification

The normal distribution tested was the loading time for C-141 aircraft. The uniform distribution tested was the time for aircrews to accomplish postflight duties in Europe prior to entering crew rest. A Kolmogorov-Smirnov goodness of fit test (Ref 26:78-79) was used to check both of these distributions. The calculations were performed using an SPSS (Statistical Package for the Social Sciences) program (Ref 14:72-74) and a table of Kolmogorov-Smirnov critical values (26:380). In both the uniform and normal tests the null hypothesis is that there is no significant difference between the observed data and that which would be given by the specified distribution with the specified parameters. The results are summarized in Figure 15.

Distribution:	Normal	Uniform
Distribution parameters:	mean = 1.3	min = 1.0
	variance = .2	max = 1.5
Sample size:	60	35
Alpha:	.05	.05
$D_{critical}$:	.175	.230
Max difference (D_{calc}):	.107	.107
Conclusion:	fail to reject H_o	fail to reject H_o

Fig. 15. Kolmogorov-Smirnov Test Results

Using these three representative examples and the results of the statistical tests, it is assumed that all computer-generated distributions within the model are performing as intended.

User-generated distributions were also checked. The four distributions are: maintenance time (event one), maintenance items (event two), supply delay (event three), and cargo weight (user function three). Because these distributions are simply sets of linear equations, statistical testing methods were not employed. Instead, the linear equations were successfully verified by hand calculation.

Another important aspect of model verification is confirming that the computer code actually performs as it was intended. To verify the computer structure, the model was run with a trace of all transactions for 48 simulated hours. Four different entities representing the four combinations of aircraft type (C-141 or C-5) and cargo type (load equipment required or not required) were followed throughout the trace; all four entities were correctly handled by the computer code.

Summary

This chapter detailed the work that was performed to validate and verify the simulation model. Because there is no historical data to compare model output with, the model validation process concentrated on input and structure validity. The procedures used to verify the internal

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workings of the model were also described. The results
from these procedures led to the conclusion that the model
is valid and functions properly.

Because the model has been validated and verified,
investigation can begin to determine those factors within
the system which have a significant impact on system capa-
bility. The procedure used to conduct this investigation
is described in Chapter IV.

IV. Experimental Design

Introduction

Any large or complex system possesses certain factors or parameters which are more important than others in regard to system output. In order to test the impact of these factors, an experimental design must be accomplished. The design chosen for this model is the 2^{k-p} fractional factorial design. This design investigates two levels of "K" factors in 2^{k-p} computer runs; "P" is a number chosen by the analyst which reduces both the number of required computer runs and establishes the degree of accuracy of the results.

There are many factors involved with this model (see Figure 16). Some of these factors can be varied, but some cannot. For example, the given flight time distribution is constant; it can't change because the aircraft's performance is relatively rigid. This type of analysis reduces the workload for this experimental design, but there are still eight factors in the model which can be varied. This would require $2^8=256$ computer runs for a full factorial. In order to choose the factors which have a chance of proving themselves important to model output, a preliminary run was accomplished with all factors at the values discussed in Chapter III. This run indicated

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LIST OF FACTORS	FIXED RATE OR DISTRIBUTION	NOT LIMITING AT PRESENT VALUE	NOT FEASIBLE TO CHANGE	POSSIBLE FACTOR
TIME IN MX	X			
# MX TEAMS REQ'D	X			
NMCM RATES	X			
TIME TO ZERO WRM				X
RESUPPLY TIME	X			X
LOAD & UNLOAD TIMES	X			
ACFT CARGO LOADS	X			
ABORT RATE	X			
ABORT MX TIMES	X			
# ACFT (1)			C5	C141
# AIRCREWS (1)		X		
FLIGHT TIMES	X			
# LOADERS (2)		X		X
# LOADCREWS (2)		X		
LOAD AVAIL RATE		X		X
# MX TEAMS				
TURNAROUND	X			

1 # aircrews tied to # aircraft
2 # loadcrews tied to # loaders

Fig. 16. MAC's Factors

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that the number of aircrews, loadcrews, or maintenance crews were not limiting to the system. The remaining factors are:

1. Time to zero WRM;

2. Resupply time distribution;

3. Number of aircraft (C-141 only);

4. Number of loaders; and

5. Load availability rate.

A full, five-factor factorial requires $2^5=32$ runs. Such a design measures the impact of each factor and also all combinations of factor interactions. Because three-factor interactions are generally negligible, the size of an experimental design may be reduced by "confounding" factors with interactions of three or more factors. For example, the result of confounding factor A with interaction BCD is that the quantified effect of factor A (as calculated by the experimental design) is actually a linear combination of the effect of factor A alone and interaction BCD alone. Therefore, if interaction BCD has a negligible effect, then confounding A with BCD does not change the calculated effect of factor A.

By confounding one factor with the remaining four, the number of simulations required is reduced by a factor of two: $2^{5-1}=2^4=16$. This could be further reduced by confounding two factors with the remaining three, but the resultant decrease in accuracy is potentially excessive

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(this is because two-factor interactions are potentially significant). The structure of the 2^{5-1} experimental design is shown in Figure 17. Each factor will be allowed to exist in one of two states denoted by "+" and "-"; the "-" values will reflect the values which exist in the current airlift system and the "+" will reflect plausible, future improvements. These improvements will be discussed individually (see Figure 18).

Factor Levels

Time to Zero WRM. Currently, time to zero WRM is given at 12 days. An arbitrary improvement factor of two is applied to give a (+) value of 24 days. This would reflect an increase in authorized WRM and would allow the airlift system to operate independently of peacetime supply during the early critical weeks of a European conflict.

Resupply Time Distribution. The current distribution is based on peacetime performance. In times of war, however, the supply system would have to improve its delivery efficiency to keep up with demand. Estimating how this increased efficiency will occur is difficult, but it is a factor which cannot be overlooked. Instead of changing the delay distribution, increased efficiency is reflected by reducing delay times to 75 percent of the current data distribution.

Number of Aircraft. As shown in Figure 18, the size of only the C-141 force will be changed. This change

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Fig. 17. Experimental Design

RUN	WRM 1	RES 2	C141 3	LDRS 4	LR 5	12	13	14	15	23	24	25	34	35	45
1	-	-	-	-	+	+	+	+	-	+	+	-	+	-	-
2	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+
3	-	+	-	-	-	-	+	+	+	-	-	-	+	+	+
4	+	+	-	-	+	+	-	-	+	-	-	+	+	-	-
5	-	-	+	-	-	+	-	+	+	-	+	+	-	-	+
6	+	-	+	-	+	-	+	-	+	-	+	-	-	+	-
7	-	+	+	-	+	-	-	+	-	+	-	+	-	+	-
8	+	+	+	-	-	+	+	-	-	+	-	-	-	-	+
9	-	-	-	+	-	+	+	-	+	+	-	+	-	+	-
10	+	-	-	+	+	-	-	+	+	+	-	-	-	-	+
11	-	+	-	+	+	-	+	-	-	-	+	+	-	-	+
12	+	+	-	+	-	+	-	+	-	-	+	-	-	+	-
13	-	-	+	+	+	+	-	-	-	-	-	-	+	+	+
14	+	-	+	+	-	-	+	+	-	-	-	+	+	-	-
15	-	+	+	+	-	-	-	-	+	+	+	-	+	-	-
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
*	2345	1345	1245	1235	1234	345	245	235	234	145	135	134	125	124	123

Columns 1–5: MAIN EFFECTS. Columns 12–45: 2-LEVEL INTERACTIONS.

* Confounded Interactions

Defining Relation: I = 12345

Independent Variable	-	FACTOR	+
1. Time to Zero WRM	12	*2	24
2. Resupply Time Distribution	current	*.75	75% current
3. Number of C-141s	176	*1.3	229
4. Number of Loaders	28	*1.5	42
5. Load Availability Rate	10 L/hr	*2	20 L/hr

Fig. 18. Improvement of Factors

is meant to reflect the increased capability of the
"stretch" C-141B. The C-141B will be able to carry thirteen
pallets of cargo instead of ten, representing an improvement
factor of 1.3 times the current capability. To accurately
reflect the improved airlift capability, new loading data
is required from the ALM. Because this is not yet avail-
able, an increase in the force size by 1.3 will be used as
a first-order approximation. Because the number of air-
crews is linked to the number of aircraft, the number of
C-141 aircrews must also be increased by a factor of 1.3

　　　　Number of Loaders. According to the preliminary
run, the number of loaders in the system creates a bottle-
neck in cargo flow. To ease this bottleneck, the number
of loaders will be doubled in the model.

Load Availability Rate. The load availability rate will also be improved by a factor of two. The real air-lift system could reflect this improvement in the model's system by upgrading aerial port facilities concerned with functions such as warehousing, pallet handling, and cargo distribution.

Expected Output

The purpose of an experimental design is to reveal those factors which significantly affect the output of the system. A critical aspect of the design, therefore, is to properly identify the output which best reflects the purpose of the system. In the case of strategic airlift, many measures of system output are applied, such as aircraft UTE rate, aircraft time on the ground, million ton-miles flown, and tons delivered (Ref 18). Because this model addresses a wartime scenario, total tons delivered is the most important measure. This measure will be applied to reveal factor effects after one month (30 days) of system operation.

Critical factors will be identified by placing the output of the experimental design into an analysis of variance (ANOVA) algorithm. The results of the ANOVA will indicate the significance level of main effects and two-factor interactions. Generally, three-factor interactions produce negligible results, so they will not be calculated.

Data Analysis

In order to determine which factors are significant in the model, a five-way ANOVA using SPSS (Ref 20:410-422) was performed. The dependent variable in the ANOVA was "total tons delivered after 30 days" as shown in Table IV. The results of the ANOVA are shown in Figure 19. These results indicate that only two of the main factors are statistically significant at the 95 percent confidence level (i.e., alpha equals .05). The two factors are factor 1 (time to zero WRM) and factor three (number of C-141s). Because factor two (resupply time) is significant at the 88.9 percent confidence level, another ANOVA was accomplished. This ANOVA run considered only the first three factors while blending the contribution of factors four and five in with the error. This run (see Figure 20) pushed the significance of resupply time up to 94.4 percent; though this is "close," it still does not meet the 95 percent criteria. Therefore, these tests lead to the conclusion that only factors one and three produce significant effects on the system, factors four and five produce negligible effects, and factor two produces only a small effect on the system. Figures 19 and 20 also indicate that there are no significant two-way interactions. This fact helps confirm the earlier assertion that there are no significant three-way or higher interactions in the system.

TABLE IV

OUTPUT SUMMARY

Run Number	Cumulative UTE Rate C-141	C-5	Total Tons Delivered (Thousands)
1A	10.63	8.80	140.7
1B	10.99	9.16	150.7
2A	12.22	10.28	164.8
2B	12.19	10.24	167.1
3A	11.03	9.02	147.2
3B	11.28	9.10	151.4
4A	12.26	10.31	163.8
4B	12.41	10.35	169.8
5A	10.59	9.05	166.6
5B	10.85	9.43	174.8
6A	12.30	10.18	190.6
6B	12.27	10.28	194.8
7A	11.07	9.31	172.4
7B	11.26	9.45	179.3
8A	12.21	10.35	191.4
8B	12.26	10.38	196.0
9A	10.73	8.93	143.5
9B	10.81	9.35	149.7
10A	12.38	10.37	166.2
10B	12.35	10.30	168.9
11A	11.16	9.00	147.5
11B	11.24	9.54	154.7
12A	12.37	10.27	166.2
12B	12.23	10.26	167.2
13A	10.72	8.99	168.3
13B	10.91	9.29	175.7
14A	12.17	10.29	191.0
14B	12.11	10.15	191.7
15A	10.98	9.05	170.4
15B	11.23	9.21	177.0
16A	12.40	10.32	194.0
16B	12.36	10.24	194.8

A = regular
B = antithetic

######## A N A L Y S I S   O F   V A R I A N C E ########
            TONS2
        BY WRM
            RESUPPLY
            C141
            LOADERS
            LOADRATE
##

SOURCE OF VARIATION		SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS		.82658E+10	5	.165E+10	103.249	.001
WRM		.29708E+10	1	.297E+10	185.547	.001
RESUPPLY		45510570.125	1	.455E+08	2.842	.111
C141		.52403E+10	1	.524E+10	327.286	.001
LOADERS		952243.000	1	952200.000	.059	.810
LOADRATE		8153703.125	1	.815E+07	.509	.486
2-WAY INTERACTIONS		29591417.000	10	.295E+07	.185	.995
WRM	RESUPPLY	14982338.000	1	.149E+08	.936	.348
WRM	C141	3889260.500	1	.388E+07	.243	.629
WRM	LOADERS	126756.125	1	126756.125	.008	.930
WRM	LOADRATE	22260.500	1	22260.500	.001	.971
RESUPPLY	C141	1031766.125	1	.103E+07	.064	.803
RESUPPLY	LOADERS	662400.500	1	662400.500	.041	.841
RESUPPLY	LOADRATE	202566.125	1	202566.125	.013	.912
C141	LOADERS	4098384.500	1	.409E+07	.256	.620
C141	LOADRATE	1072380.125	1	.107E+07	.067	.799
LOADERS	LOADRATE	3503304.500	1	.350E+07	.219	.646
EXPLAINED		.82954E+10	15	.553E+09	34.539	.001
RESIDUAL		.25616E+09	16	.160E+08		
TOTAL		.85516E+10	31	.275E+09		

32 CASES WERE PROCESSED.
0 CASES (0 PCT) WERE MISSING.

Fig. 19.   Five-Way ANOVA

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```
********* A N A L Y S I S   O F   V A R I A N C E *********
          TONS2
        BY WRN
          RESUPPLY
          C141
***************************************************************

                                SUN OF              MEAN        SIGNIF
SOURCE OF VARIATION             SQUARES    DF      SQUARE    F    OF F

  MAIN EFFECTS                 .82567E+18    3  .275E+18 243.318   .001
    WRN                        .29708E+18    1  .297E+18 262.647   .001
    RESUPPLY                  45510570.125   1  .455E+08   4.023   .056
    C141                       .52403E+18    1  .524E+18 463.283   .001

  2-WAY INTERACTIONS          19903364.625   3  .663E+07    .587   .630
    WRN      RESUPPLY         14982338.000   1  .149E+08  1.325   .261
    WRN      C141              3889260.500   1  .388E+07    .344   .563
    RESUPPLY C141             1031766.125    1  .103E+07    .091   .765

  3-WAY INTERACTIONS           3503304.500   1  .350E+07    .310   .583
    WRN      RESUPPLY C141     3503304.500   1  .350E+07    .310   .583

  EXPLAINED                    .82801E+18    7  .118E+18 104.575   .001

  RESIDUAL                     .27147E+09   24  .113E+08

  TOTAL                        .85516E+18   31  .275E+09


    32 CASES WERE PROCESSED.
     0 CASES (    0 PCT) WERE MISSING.
```

Fig. 20. Three-Way ANOVA

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The effects of the various factors are more clearly displayed in Figure 21. This figure is a ranked plot of the total tons delivered for the different runs made under the regular seeds ("+" symbols) and the antithetic seeds ("-" symbols). Note that there are 17 runs plotted; the extra run (over the 16 runs in the experimental design) represents the "nominal" run made. The positive factors associated with each data point are listed under the axis for easier interpretation. For example, on the run ranked number six, factors 1, 2, and 5 were at improved levels for the regular run, and only factor 1 was improved for the antithetic run. By dividing the plot into four cells, factor effects are highlighted. The first cell has a mean of 147,770 tons and represents the nominal runs and experimental runs 1, 3, 9 and 11. Because this cell has factors 1 and 3 at minus levels, it is considered the base level to which any improvements will be compared. The second cell encompasses runs 2, 4, 10, and 12 with only the time to zero WRM at the improved level. The cell mean of 166,746 tons indicates that the effect of increased WRM alone results in a 12.8 percent improvement in the output. Similarly, the third cell, representing runs 5, 7, 13, and 15 with only the number of C-141s improved, has a cell mean of 173,069 tons. This represents a 17.1 percent increase over the base level. Finally, the fourth cell encompasses runs 6, 8, 14, and 16 with both factors at improved levels.
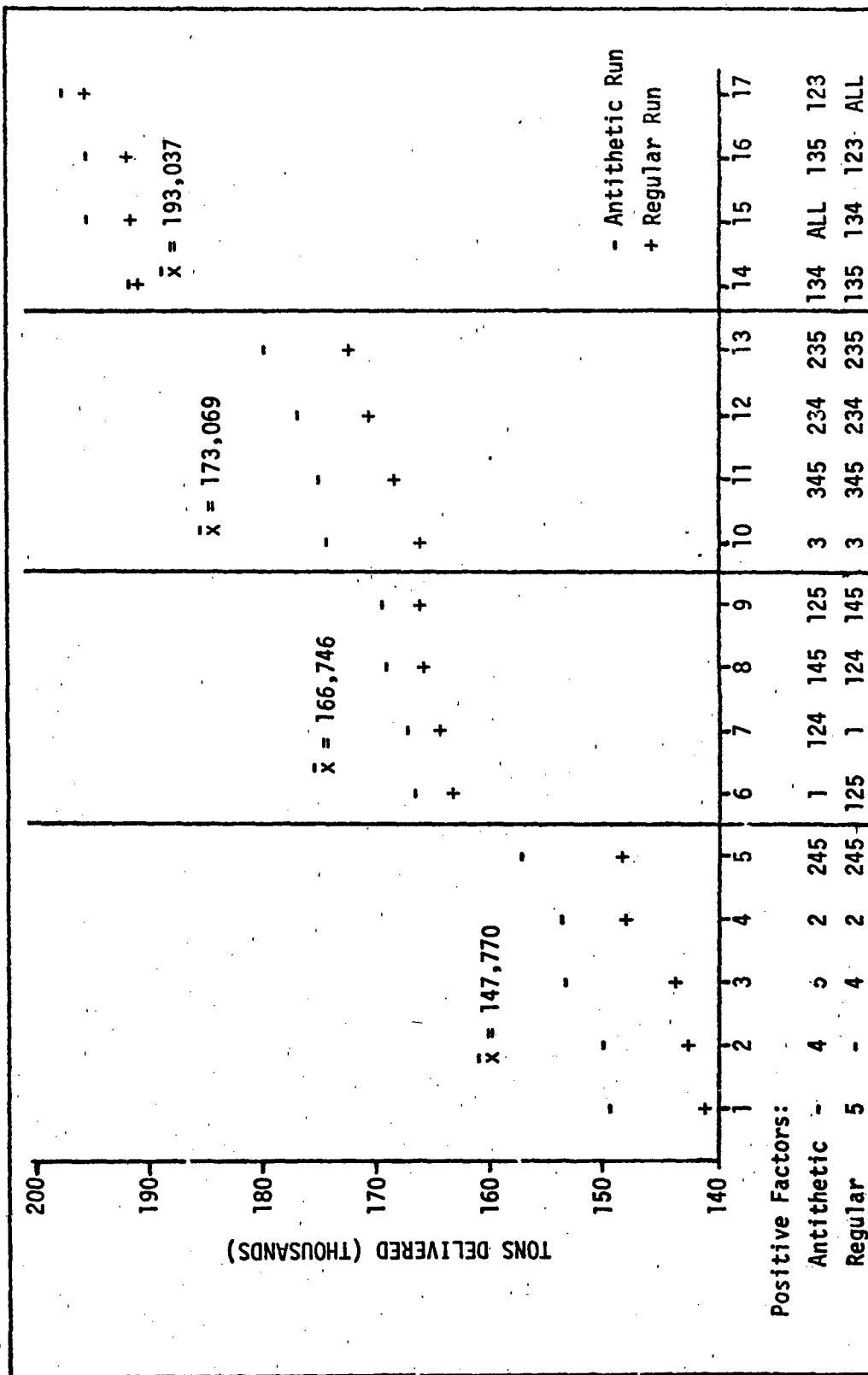
Fig. 21. Ranked Results of Output

TONS DELIVERED (THOUSANDS)

$\bar{x} = 147,770$

$\bar{x} = 166,746$

$\bar{x} = 173,069$

$\bar{x} = 193,037$

- Antithetic Run
+ Regular Run

Positive Factors:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Antithetic -		4	5	2	245	1	124	145	125	3	345	234	235	134	ALL	135	123
Regular 5			4	2	245	125	1	124	145	3	345	234	235	135	134	123	ALL

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This cell mean of 195,037 tons is a 30.6 percent improvement over cell one. Another point is brought out by Figure 21 and deserves mentioning. Note that within each cell, there is a tendency for the data points to slope upward. This may be the effect of factor two (resupply time) which was discussed earlier; with the exception of the second cell, only the elevated end of each cell has resupply time at an improved level. The effect of changing the time to zero WRM or the number of C-141s is more clearly displayed in Figures 22 and 23. These bar graphs show the effect of changing one factor when the other factor is held constant at each of its two possible levels.

Even though increases in output can be made by either changing the time to zero WRM or the number of C-141s, the effect on other parts of the system is not the same. Table V shows that the change in the number of C-141s increases the output by an average of 16.5 percent with no significant change in the aircraft UTE rate or the average flying hours per aircrew. Conversely, the effect of changing zero WRM time results in a 12.1 percent average increase in output, and also creates approximately a 12 percent increase in aircraft UTE rate and average flying hours per aircrew. This increase results in UTE rates of 12.3 hours for the C-141 and 10.3 hours for the C-5. Both of these rates are below the 12.5 hour UTE rate used as a wartime planning factor (Ref 27) and hence should not

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12 Days to Zero WRM

Number of C-141's

229 — 173.1

% Change = 17.1

176 — 148.7

100   200

Total Tons of Cargo Delivered
(thousands)

24 Days to Zero WRM

Number of C-141's

229 — 193.0

% Change = 15.8

176 — 166.8

100   200

Total Tons of Cargo Delivered
(thousands)
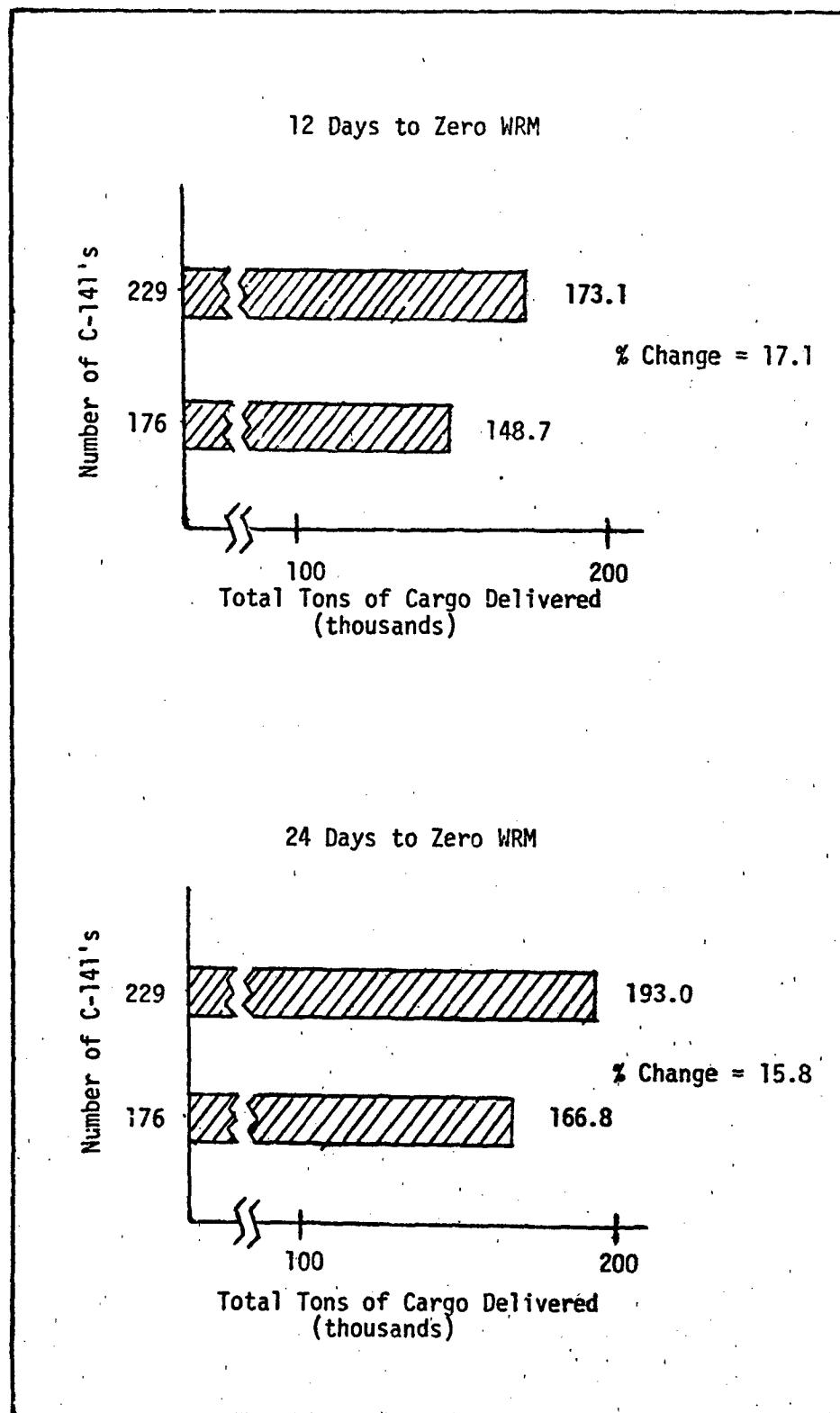
Fig. 22.   Total Tons Delivered versus C-141 Level

176 C-141's

Time to Zero WRM
(days)

24 166.8

% Change = 12.8

12 148.7

100   200

Total Tons of Cargo Delivered
(thousands)

229 C-141's

Time to Zero WRM
(days)

24 193.0

% Change = 11.5

12 173.1

100   200

Total Tons of Cargo Delivered
(thousands)
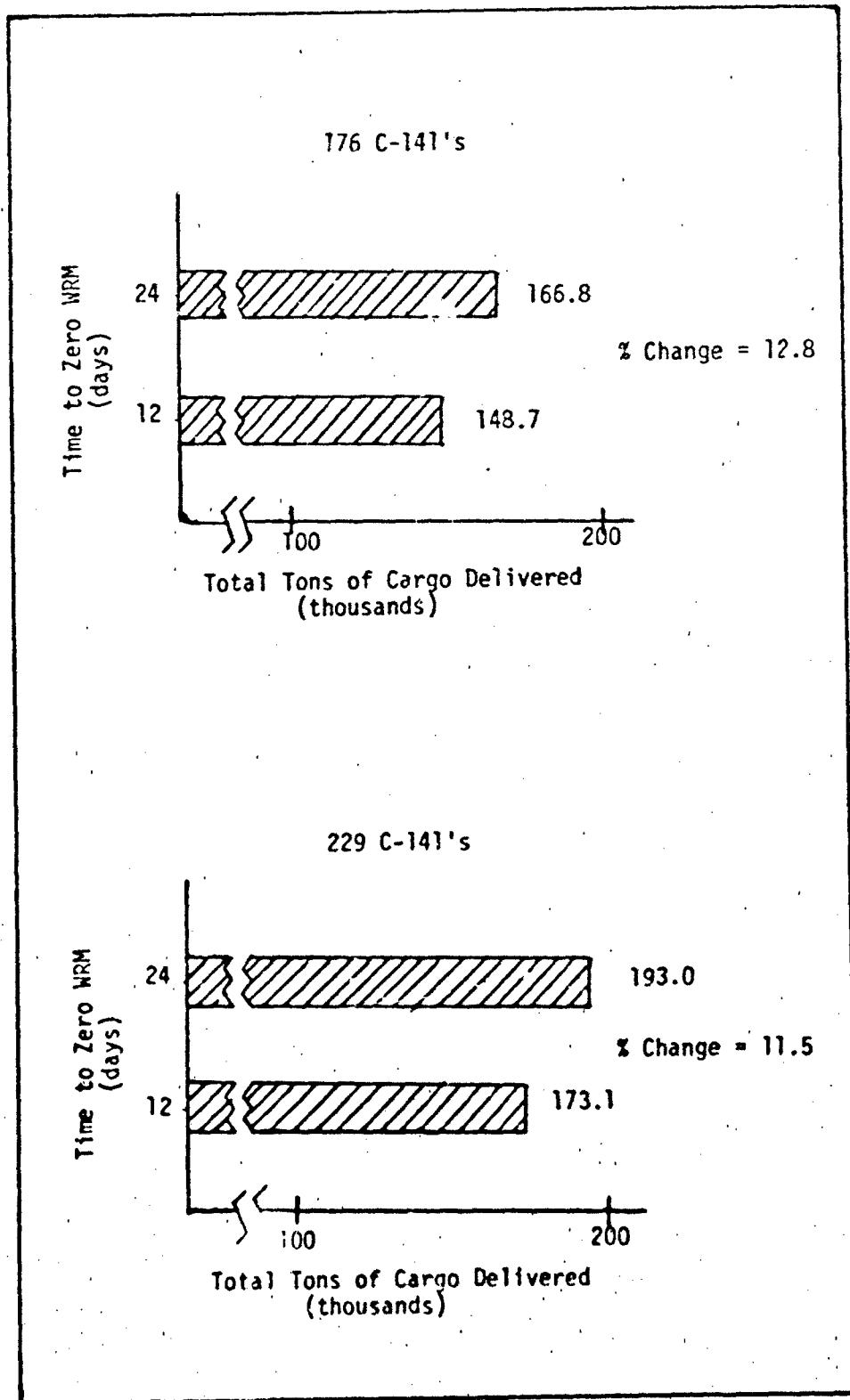
Fig. 23. Total Tons Delivered versus WRM Level

TABLE V

EFFECT ON WRM AND C-141 LEVELS ON UTE RATE AND FLYING HOURS

Factor Level WRM	Factor Level C-141	Avg Output (Thousands)	% Change (Output)	Average (UTE Rate) C-141	Average (UTE Rate) C-5	% Change (UTE Rate) C-141	% Change (UTE Rate) C-5	Avg Flying Hrs Per Aircrew C-141	Avg Flying Hrs Per Aircrew C-5	% Change (Flying Hrs) C-141	% Change (Flying Hrs) C-5
-	-	148.7		10.98	9.11			82.38	84.00		
-	+	173.1	17.0	10.95	9.22	-0.3	1.2	82.13	85.26	-0.3	1.5
+	+	166.8		12.30	10.30			92.26	95.19		
+	+	193.0	15.8	12.26	10.27	-0.3	-0.3	91.95	94.97	-0.3	0.2
-	-	148.7		10.98	9.11			82.38	84.00		
+	-	166.8	12.8	12.30	10.30	12.0	13.1	92.26	95.19	12.0	13.3
-	+	173.1		10.95	9.22			82.13	85.26		
+	+	193.0	11.5	12.26	10.27	12.0	13.1	91.95	94.97	12.0	11.4

create a strain on the system. The 12 percent increase in average flying hours per aircrew results in a change from 82-84 hours per crew to 92-95 hours per crew. When average aircrew flying hours are at their peacetime level of 30-40 hours per month (Ref 18:OPS37-41) a 1 average increase of 10 flying hours per aircrew will not cause a strain on the system. However, when flying hours per aircrew are already twice the peacetime average, an additional 10 hours per cru does make an important difference. With the average flying hours per crew at 82 hours, it is possible that some crews will be at or near the maximum limit for each crew-member of 125 flying hours in any consecutive 30-day period (Ref 4:7-1). When the average flying hours per crew are raised to 92-95 hours, even more crews will be at or near the 125-hour limit. This means that either some crews will be unavailable to fly for a period of time, or that the limit must be waived. While the 125-hour limit can be waived, such a waiver may induce the risk of decreased aircrew proficiency due to fatigue. Also, if the 125-hour limit is not waived, an increase in the average flying hours per crew in the early part of an extended airlift will have an effect on aircrew availability in the longer term. This problem is somewhat mitigated when the time to zero WRM is reached. At that point, resupply time requires aircraft to spend more time in maintenance and hence the UTE rate and flying hours will go down. The contrast between the

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effects of changes in the time to zero WRM and the number of C-141s points out the fact that although output level is the main criterion being evaluated, the effects on other parts of the system must also be considered.

Summary

This chapter first described the experimental design and the preliminary analysis which indicated the factors to be considered in the experimental design. Each factor and the change to that factor was described. Next, the data analysis performed after the design was completed was discussed. This analysis indicated that: time to zero WRM and the number of C-141s are statistically significant factors in regards to system capability; resupply time appears to have some influence, even though it is not statistically significant; and that the number of loaders and load availability rate have no statistically significant effect on the system. Further analysis on the significant factors also showed that changes in these factors produced different effects on other aspects of system operation.

Based on the data analysis, several conclusions and recommendations can be made. These conclusions and recommendations are presented in Chapter V.

V. Conclusions and Recommendations

Summary

Examined in this study was the wartime capability of the MAC airlift system. Specifically, the capability of the strategic airlift system in support of a war in Europe is considered. Major subsystems within the overall airlift system were identified and described, with emphasis placed on the ability of the system to move cargo from one point to another. Using available data for peacetime operations as a starting point, input data for a wartime scenario was generated. A simulation model was then developed to capture the important activities that take place as cargo moves through the system. The model also identifies those factors that are most critical to system operation. Various runs of the model were made to determine the effect on the output by changes in certain parameters. Analysis of the model outputs allows several conclusions to be drawn.

Conclusions

Model Viability. Based on the results of this thesis, the concept of approaching airlift system capability with a fairly simple simulation model is a viable approach. Although all the detail of the system is not included, general estimates of system capability can still

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be made. In many cases, the value of a small, workable model that gives approximate results may be worth the loss of the detail contained in larger models.

Significant Factors. To the extent that the model portrays the significant elements within the wartime strategic airlift system, the time to zero WRM and the number of aircraft available are the factors that have the most significant impact on system capability in terms of total tons of cargo delivered. If additional WRM is available, the system capability can be increased. However, an increased demand is put on both aircraft and crew in terms of UTE rate and flying hours. The capability can also be increased by increasing the number of aircraft and aircrews available for the specific scenario. In this case, the increased capability is achieved without any increased demand on individual aircraft and crews.

UTE Rate. The use of UTE rate is only an indirect measure of the capability of the system. The UTE rate and the size of the force must be considered together if UTE rate is to serve as a reliable indicator of system capability.

Number of Aircraft. Although the effect of increasing only the number of C-141 aircraft was considered, increasing the number of C-5 aircraft available would also have a positive effect on capability. The increase in the number of C-141s was designed to reflect the additional

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capability of the "stretched" C-141B. However, the number
of C-141s and C-5s was initially limited in the model to
75 percent of the total force (the rest being required for
other commitments). Therefore, the increase in the number
of C-141s could also reflect a change in priorities and
the assignment of more aircraft to the European airlift
mission. Following the same logic, the number of C-5s
could also be increased. The fact that the number of air-
craft has a significant effect on the system capability is
especially important because this is one factor that can
be changed quickly in a time of crisis.

Recommendations

This thesis is a first step in developing a way to
consider the wartime capability of the strategic airlift
system as a whole instead of looking separately at indi-
vidual parts. Since it is a first step, there are several
areas where further investigation could be made.

Number of Bases. Instead of using one aggregate
base in the U.S. and one in Europe, two or three bases in
each area could be modeled. In the U.S., some combination
of strategic airlift bases on the East Coast and other
likely ports of embarkation could be modeled. This multiple
base approach allows for the possibility of unequal distri-
bution of resources and the effect of this distribution on
the system. In the same manner, two or three bases in
Europe could be modeled to explore the effects of resource

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division among different ports of debarkation. However, the value to be gained by modeling additional bases must be carefully considered. This is because the complexity of the model grows in an exponential fashion as the number of bases is increased.

Attrition. Another area for future analysis is the effect of loss or attrition of resources. This thesis considered only positive changes in resource levels. In a wartime scenario, it is not unreasonable to assume that some resources will be either temporarily or permanently unuseable. This concept could be tied in with the multiple base approach by considering the effect of the loss of resources at one particular base.

Maintenance. The entire maintenance subsystem needs more investigation. In developing the model the best information that could be obtained concerning maintenance was used. When the model was run, no more than 65 percent of the available maintenance crews were ever in use by the system; however, MAC's authorized maintenance strength does exist as outlined in the maintenance personnel section of Chapter III. The implication is that either less maintenance personnel are needed, or the maintenance requirements have not been accurately captured by the model.

Value to MAC. If airlift system capability was approached using "tons delivered" instead of UTE rate, a direct measure of system capability would be available.

This would enhance MAC planning by eliminating the need for the transformation between UTE rate and cargo delivered. The end result would be a more direct link between the input factors and the real capability of the airlift system.

Implementation of Results. Based on the results of this thesis, it is recommended that the Military Airlift Command concentrate its efforts on completing the "stretch" C-141B program as rapidly as possible and continue its efforts towards acquiring the C-X. Additionally, supply is critical to extended airlift operations and, therefore, should be bolstered to the maximum extent possible.

Comment

There is a tremendous need to know what to expect of military airlift under "wartime rules." Because actual exercises may be prohibitively expensive, some of this data must be obtained from routine, peacetime activity. For example, the need exists to know how often an aircraft will require maintenance on MESL systems, how long it will take to repair these systems, and what resources are required (both manpower and parts) to effect repair. Currently, data is available only on peacetime maintenance, and not enough effort has been spent in extracting wartime maintenance requirements from this data. Supply data is equally ellusive.

The value of this model does not lie only in the output. The biggest value is the effort behind the model: the research, the techniques used, and the conclusions made. It has been said that the greatest value of modeling or simulation is the understanding gained of the system being studied. Such is the case with this model. Anyone desiring to use this model in the future would do well to use it as a starting point to tailor their own model to address their own specific needs.

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Appendix A

Network Diagrams and Computer Code
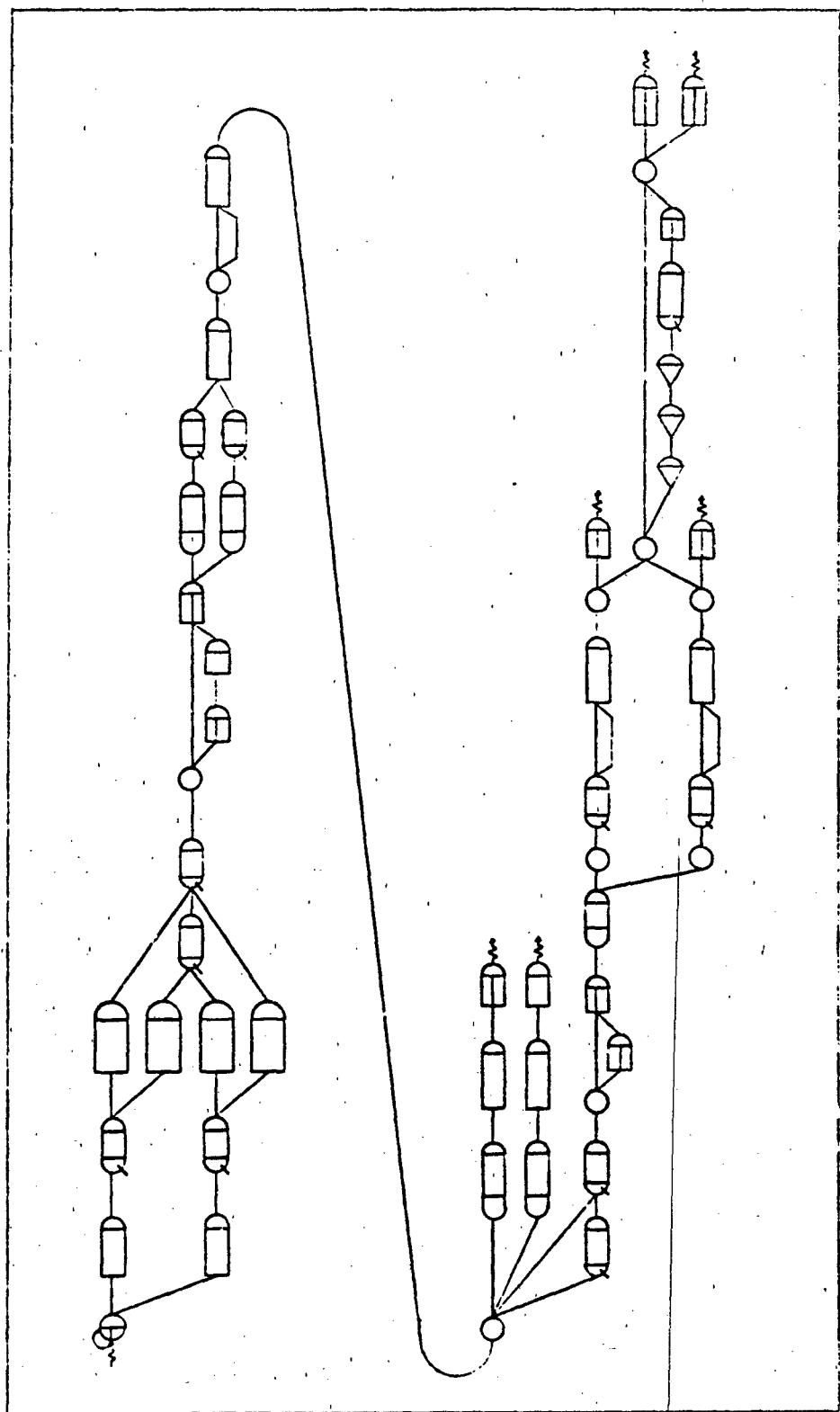
Fig. 24. SLAM Network
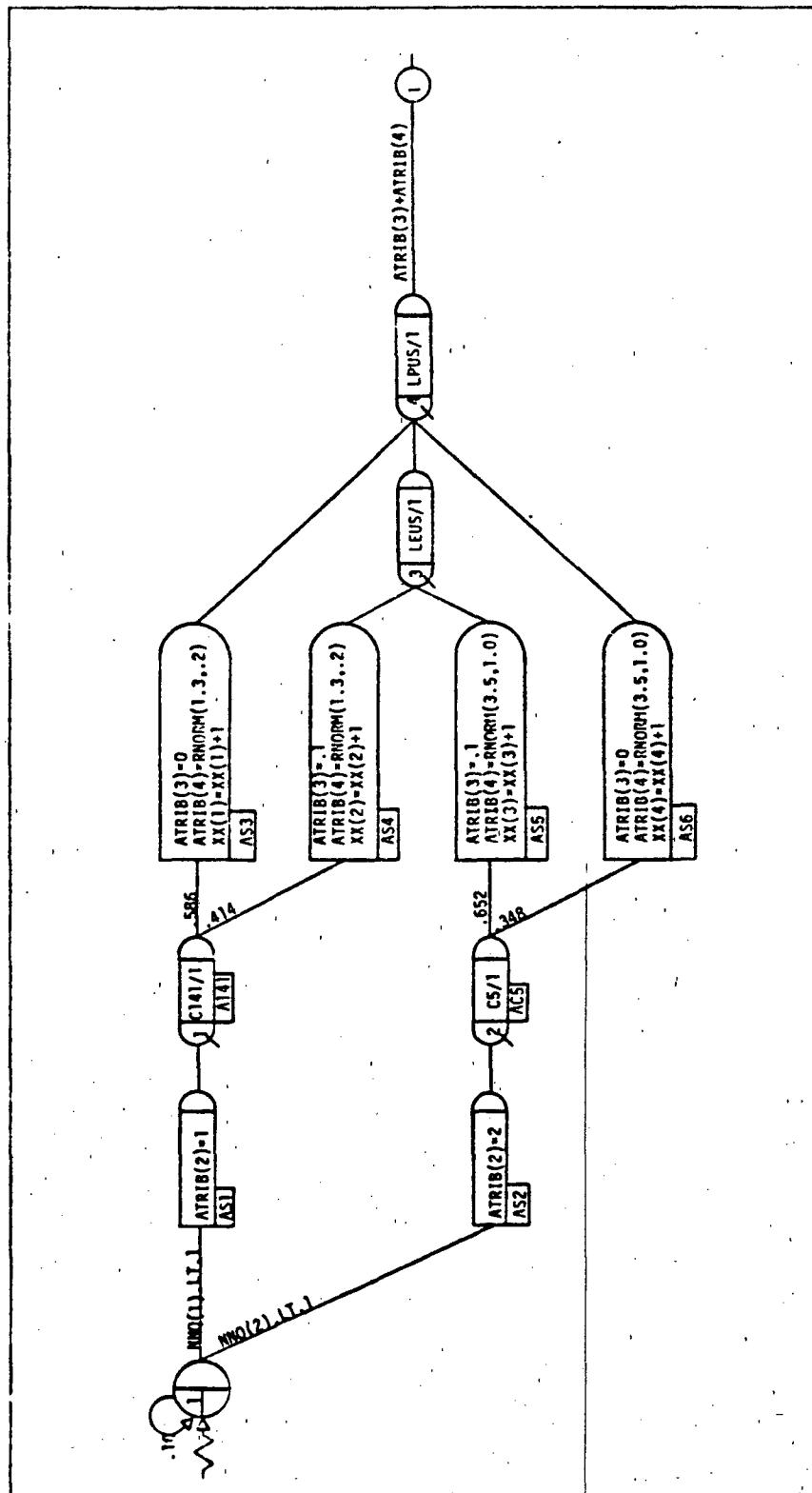
Fig. 24--Continued
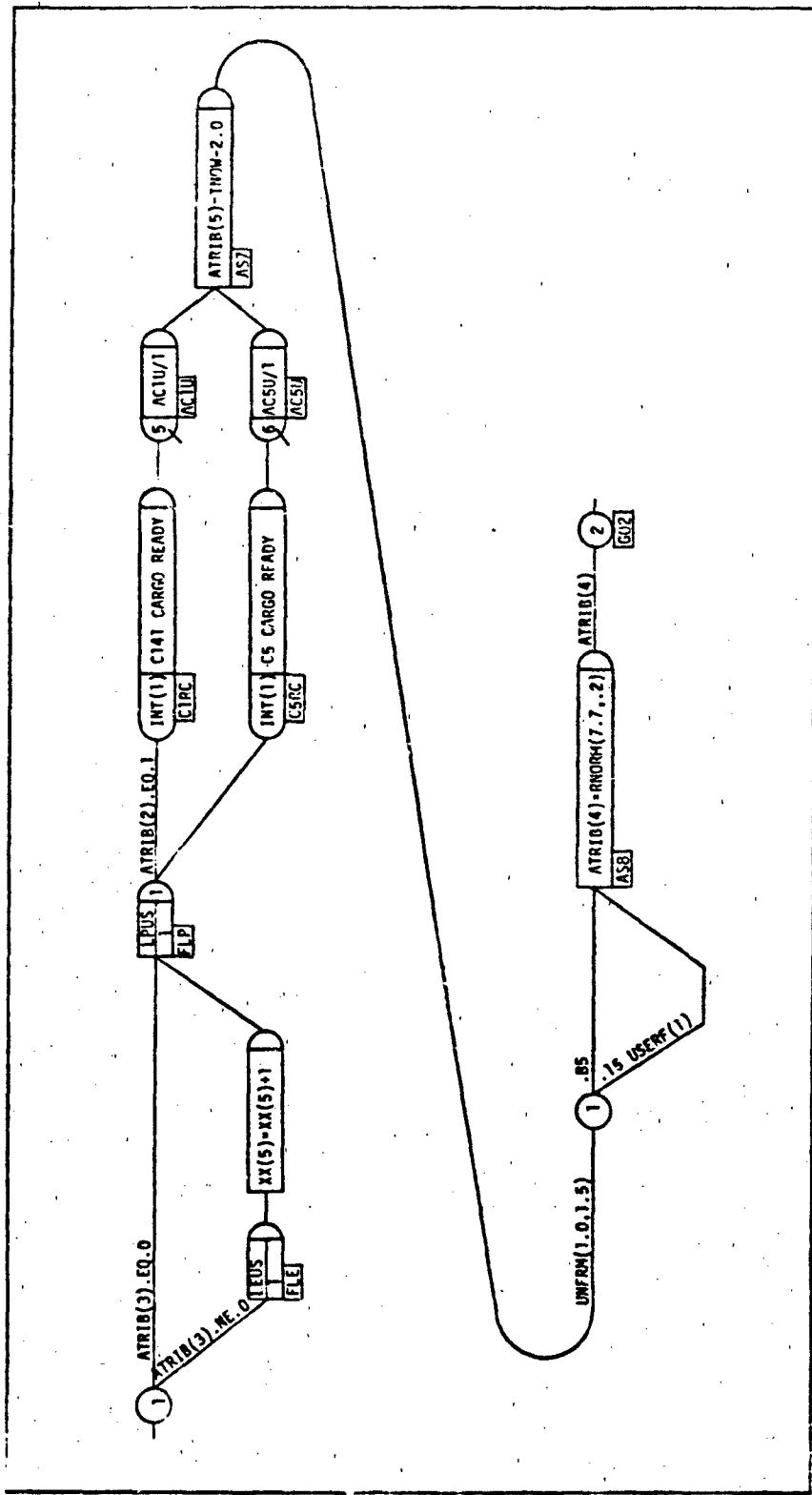
Fig. 24--Continued
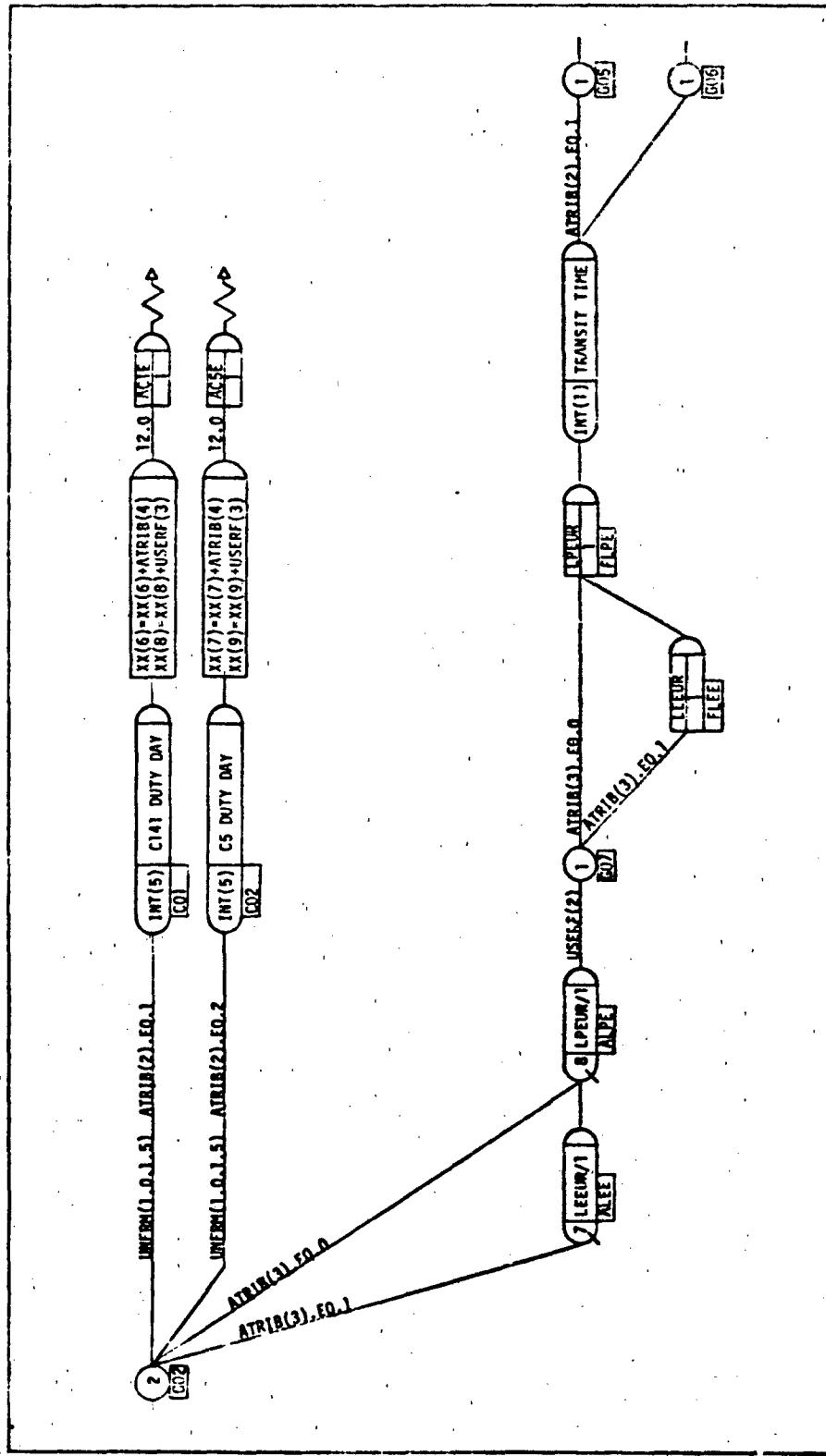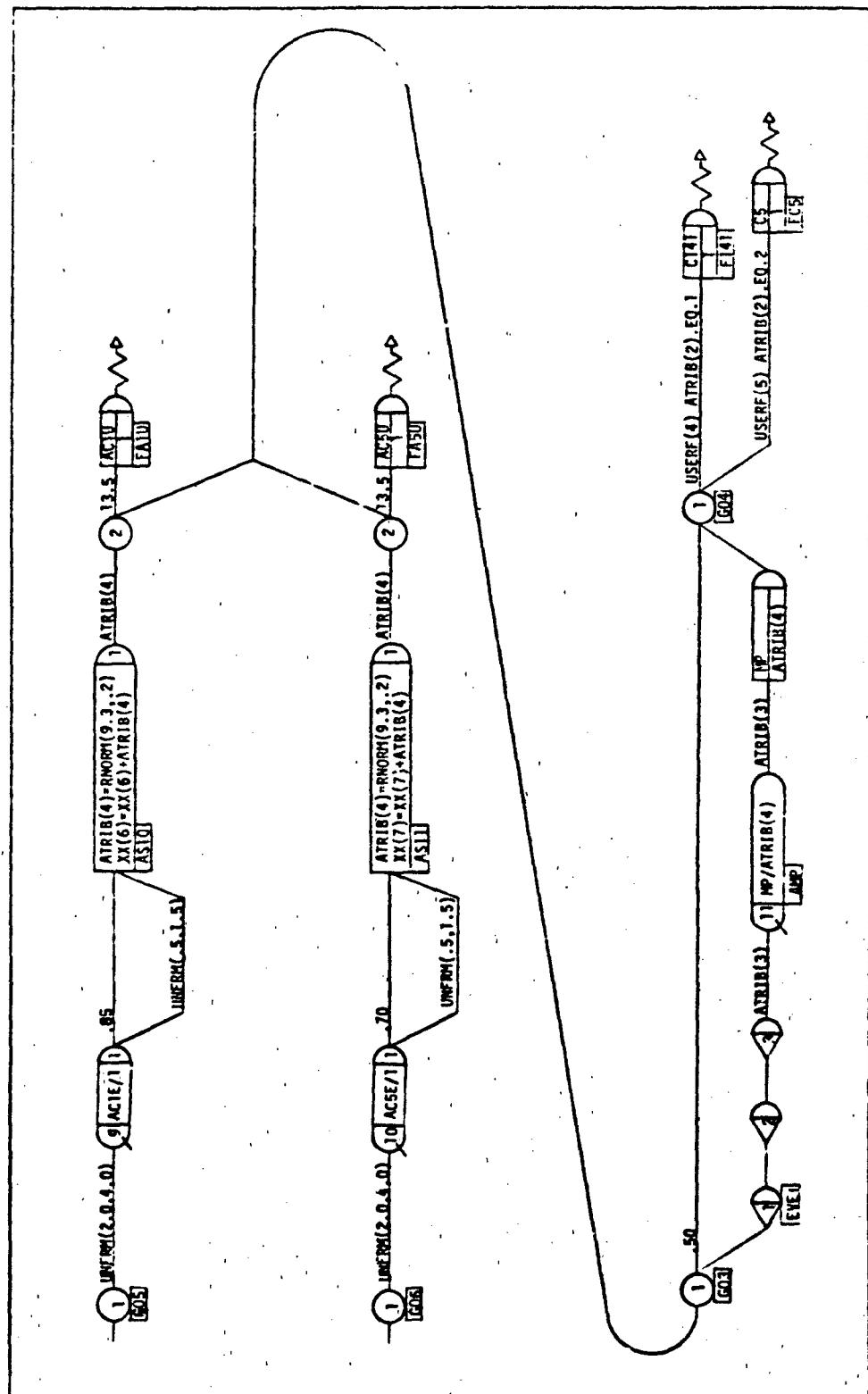
Fig. 24--Continued

Fig. 24--Continued

```
EKH,T500,CM165000,STCSA.    T790554,HOLCK,4423                  00100
  ATTACH,PROCFIL,SLAMPROC,ID=AFIT.                             00110
  FTN,SYSEDIT.                                                 00120
  BEGIN,SLAM,,M=LGO,PMD=PMD,PL=10000.                          00130

*EOR
        PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)  00150
        DIMENSION NSET (22000)                                 00160
        COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR  00170
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)  00180
        COMMON QSET (22000)                                    00190
        EQUIVALENCE (NSET(1),QSET(1))                          00200
        NNSET=22000                                            00210
        NCRDR=5                                                00220
        NPRNT=6                                                00230
        NTAPE=7                                                00240
        CALL SLAM                                              00250
        STOP                                                   00260
        END                                                    00270
C                                                              00280
C                                                              00290
        SUBROUTINE EVENT (I)                                   00300
        COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR  00310
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)  00320
        COMMON/EVENT4/CTD1,CUTE1,FLYN5,FLYT5,TD1,TODAY,        00330
       *TONN5,TONT5,UTE5,CTD,CTD5,CUTE5,FLYN1,FLYT1,           00340
       *TD,TD5,TONN1,TONT1,UTE1                                00350
        GO TO (1,2,3,4),I                                      00360
C                                                              00370
C  EVENT 1.   THIS IS USED TO DETERMINE HOW MUCH TIME          00380
C             AN ACFT WILL REQUIRE WHILE IN MAINTENANCE.       00390
C                                                              00400
1       X=DRAND(1)                                             00410
        IF (X.LE..4638) GO TO 101                              00420
        IF (X.LE..6240) GO TO 102                              00430
        IF (X.LE..7675) GO TO 103                              00440
        IF (X.LE..9355) GO TO 104                              00450
        GO TO 105                                              00460
101     ATRIB(3)= X*4.31 + 1.0                                 00470
        RETURN                                                 00480
102     ATRIB(3)=(X-.4638) * 18.73 + 3.0                       00490
        RETURN                                                 00500
103     ATRIB(3)=(X-.6240) * 93.62 + 6.0                       00510
        RETURN                                                 00520
104     ATRIB(3)=(X-.7675) * 47.62 + 18.                       00530
        RETURN                                                 00540
105     ATRIB(3)=(X-.9355) * 155.04 + 26.                      00550
        RETURN                                                 00560
C                                                              00570
C                                                              00580
C  EVENT 2.   THIS EVENT IS USED TO DETERMINE HOW MANY MAINTENANCE  00590
C             ITEMS (AND, HENCE, MAINTENANCE TEAMS) AN ACFT HAS.    00600
C                                                              00610
```

```
2       X=DRAND(2)                                          00620
        IF (X.LE..588) GO TO 201                            00630
        IF (X.LE..722) GO TO 202                            00640
        IF (X.LE..761) GO TO 203                            00650
        IF (X.LE..873) GO TO 204                            00660
        IF (X.LE..915) GO TO 205                            00670
        IF (X.LE..949) GO TO 206                            00680
        IF (X.LE..966) GO TO 207                            00690
        IF (X.LE..983) GO TO 208                            00700
        IF (X.LE..991) GO TO 209                            00710
        GO TO 210                                           00720
201     ATRIB(4) = 1                                        00730
        RETURN                                              00740
202     ATRIB(4) = 2                                        00750
        RETURN                                              00760
203     ATRIB(4) = 3                                        00770
        RETURN                                              00780
204     ATRIB(4) = 4                                        00790
        RETURN                                              00800
205     ATRIB(4) = 5                                        00810
        RETURN                                              00820
206     ATRIB(4) = 6                                        00830
        RETURN                                              00840
207     ATRIB(4) = 7                                        00850
        RETURN                                              00860
208     ATRIB(4) = 8                                        00870
        RETURN                                              00880
209     ATRIB(4) = 9                                        00890
        RETURN                                              00900
210     ATRIB(4) = 10                                       00910
        RETURN                                              00920
C                                                           00930
C                                                           00940
C  EVENT 3.  THIS EVENT IS USED TO DETERMINE HOW LONG AN ACFT   00950
C            IS DOWN WHILE WAITING FOR SUPPLY.  NOTE THAT SUPPLY 00960
C            IS NOT A FACTOR FOR THE FIRST 12 DAYS (288 HOURS)   00970
C            THIS IS DUE TO LOCAL STOCK AND WRSK STOCKPILES.     00980
C                                                           00990
C** FIRST,DETERMINE IF SUPPLY IS A FACTOR:                  01000
C                                                           01010
3       IF (DRAND(3).LE..75) GO TO 300                      01020
        IF (TNOW.LE.288) GO TO 300                          01030
C                                                           01040
C** FOR THE C141 **************                             01050
C                                                           01060
        IF (ATRIB(2).EQ.2) GO TO 30                         01070
        X=DRAND(3)                                          01080
        IF (X.LE..004) GO TO 301                            01090
        IF (X.LE..330) GO TO 302                            01100
        GO TO 303                                           01110
300     ATRIB(5)=0                                          01120
        RETURN                                              01130
301     ATRIB(5)=(6000.*(X) + 24.)*1.0                      01140
```

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```
          RETURN                                                   01150
302    ATRIB(5)=(73.62*(X-.004) + 48.)*1.0                         01160
          RETURN                                                   01170
303    ATRIB(5)=(143.20*(X-.330) + 72.)*1.0                        01180
          RETURN                                                   01190
C                                                                  01200
C** FOR THE C5 *****************                                   01210
C                                                                  01220
30     X=DRAND(3)                                                  01230
          IF (X.LE..002) GO TO 304                                 01240
          IF (X.LE..233) GO TO 305                                 01250
          IF (X.LE..323) GO TO 306                                 01260
          IF (X.LE..338) GO TO 307                                 01270
          IF (X.LE..585) GO TO 308                                 01280
          GO TO 309                                                01290
304    ATRIB(5)=(12000.*(X) + 24.)*1.0                             01300
          RETURN                                                   01310
305    ATRIB(5)=(103.9*(X-.002) + 48.)*1.0                         01320
          RETURN                                                   01330
306    ATRIB(5)=(266.67*(X-.233) + 72.)*1.0                        01340
          RETURN                                                   01350
307    ATRIB(5)=(1600.*(X-.323) + 96.)*1.0                         01360
          RETURN                                                   01370
308    ATRIB(5)=(97.17*(X-.338) + 120.)*1.0                        01380
          RETURN                                                   01390
309    ATRIB(5)=(57.83*(X-.585) + 144.)*1.0                        01400
          RETURN                                                   01410
C                                                                  01420
C                                                                  01430
C   EVENT 4.   THIS EVENT CALCULATES AND PRINTS DAILY UTE          01440
C              RATES, CUMULATIVE UTE RATES, DAILY TONS/DAY,        01450
C              CUMULATIVE TONS/DAY, AND TOTAL TONNAGE ON A         01460
C              DAILY BASIS.                                        01470
C                        ---N1 = CURRENT C141 FLY TIME/TONNAGE     01480
C                        ---T1 = YESTERDAY'S C141 FLYTIME/TONNAGE  01490
C                        ---N5 = CURRENT C5 FLY TIME/TONNAGE       01500
C                        ---T5 = YESTERDAY'S C5 FLY TIME/TONNAGE   01510
C                        UTE = UTILIZATON (HRS/ACFT/DAY)           01520
C                        TD = TONS/DAY                             01530
C                                                                  01540
4      IF (TNOW.NE.24.) GO TO 40                                   01550
          FLYN1=0.                                                 01560
          TONN1=0.                                                 01570
          FLYN5=0.                                                 01580
          TONN5=0.                                                 01590
40     TODAY=TNOW/24.                                              01600
          FLYT1=FLYN1                                              01610
          FLYN1=XX(6)                                             01620
          UTE1=(FLYN1-FLYT1)/176.                                 01630
          CUTE1=FLYN1/176./TODAY                                  01640
          TONT1=TONN1                                             01650
          TONN1=XX(8)                                             01660
          TD1=TONN1-TONT1                                         01670
          CTD1=TONN1/TODAY                                        01680
```

```
C                                                                    01690
      FLYT5=FLYN5                                                     01700
      FLYN5=XX(7)                                                     01710
      UTE5=(FLYN5-FLYT5)/53.                                          01720
      CUTE5=FLYN5/53./TODAY                                           01730
      TONT5=TONN5                                                     01740
      TONN5=XX(9)                                                     01750
      TD5=TONN5-TONT5                                                 01760
      CTD5=TONN5/TODAY                                                01770
C                                                                    01780
      TOTAL=XX(8)+XX(9)                                               01790
      TD=TD1+TD5                                                      01800
      CTD=CTD1+CTD5                                                   01810
401   FORMAT (/," DAY ",F3.0,33X,"C141",7X,"C5")                      01820
402   FORMAT (7X,"UTE PAST 24 HRS",12X,":",5X,F5.2,5X,F5.2)           01830
403   FORMAT (7X,"CUMULATIVE UTE",13X,":     ",F5.2,5X,F5.2)          01840
404   FORMAT (7X,"TON/DAY PAST 24 HRS",8X,":     ",F5.0,5X,F5.0)      01850
405   FORMAT (7X,"CUMULATIVE TONS/DAY",8X,":     ",F5.0,5X,F5.0)      01860
406   FORMAT (7X,"TOTAL TONS/DAY PAST 24 HRS :",18X,F5.0)             01870
407   FORMAT (7X,"TOTAL CUMULATIVE TONS/DAY  :",18X,F5.0)             01880
408   FORMAT (7X,"TOTAL TONS DELIVERED",7X,":",8X,F7.0)               01890
      PRINT 401,TODAY                                                 01900
      PRINT 402,UTE1,UTE5                                             01910
      PRINT 403,CUTE1,CUTE5                                           01920
      PRINT 404,TD1,TD5                                               01930
      PRINT 405,CTD1,CTD5                                             01940
      PRINT 406,TD                                                    01950
      PRINT 407,CTD                                                   01960
      PRINT 408,TOTAL                                                 01970
      RETURN                                                          01980
      END                                                             01990
C                                                                    02000
C                                                                    02010
      FUNCTION USERF(I)                                               02020
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR 02030
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100) 02040
      GO TO (1,2,3,4,5),I                                             02050
C *****************************************************                02060
C ** DETERMINE ASORT MAINTENANCE TIME **                              02070
C *****************************************************                02080
1     USERF=DRAND(1) + .5                                             02090
      RETURN                                                          02100
C *****************************************************                02110
C ** DETERMINE OFFLOAD TIMES FOR C141 **                              02120
C *****************************************************                02130
2     IF (ATRIB(2).EQ.2) GO TO 22                                     02140
      IF (DRAND(1).LE..732) GO TO 21                                  02150
C ** OFFLOAD TIME FOR C141 BULK CARGO                                 02160
      USERF = RNORM (1.0,.2,1)                                        02170
      RETURN                                                          02180
C ** OFFLOAD TIME FOR C141 OVERSIZE CARGO                             02190
21    USERF = RNORM (.84,.2,1)                                        02200
      RETURN                                                          02210
C*****************************************************                 02220
```

```
C** DETERMINE OFFLOAD TIMES FOR C5 **                              02230
C**:]******************************                                02240
22     X = DRAND(1)                                                02250
       IF (X.LE..615) GO TO 23                                     02260
       IF (X.LE..775) GO TO 24                                     02270
C ** OFFLOAD TIME FOR C5 BULK CARGO                                02280
       USERF = RNORM (3.0,.5,1)                                    02290
       RETURN                                                      02300
C ** OFFLOAD TIME FOR C5 OVERSIZE CARGO                            02310
23     USERF = RNORM (2.44,.9,1)                                   02320
       IF (USERF.LT..7.OR.USERF.GT.5.8) GO TO 23                   02330
       RETURN                                                      02340
C ** OFFLOAD TIME FOR C5 OUTSIZE CARGO                             02350
24     USERF = RNORM (2.3,.9,1)                                    02360
       IF (USERF.LT..5.OR.USERF.GT.6.0) GO TO 24                   02370
       RETURN                                                      02380
C ************************************                             02390
C ** DETERMINE CARGO WEIGHT IN TONS **                            02400
C ************************************                             02410
3      IF (ATRIB(2).EQ.1) GO TO 31                                 02420
C ** FOR THE C5 ****************                                   02430
       X=DRAND(5)                                                  02440
       IF (X.LE..500) GO TO 41                                     02450
       IF (X.LE..923) GO TO 42                                     02460
       GO TO 43                                                    02470
41     X=DRAND(6)                                                  02480
       IF (X.LE..1111) GO TO 411                                   02490
       IF (X.LE..1715) GO TO 412                                   02500
       IF (X.LE..1783) GO TO 413                                   02510
       GO TO 414                                                   02520
42     X=DRAND(7)                                                  02530
       IF (X.LE..2302) GO TO 421                                   02540
       IF (X.LE..3786) GO TO 422                                   02550
       IF (X.LE..5216) GO TO 423                                   02560
       IF (X.LE..6172) GO TO 424                                   02570
       IF (X.LE..6549) GO TO 425                                   02580
       IF (X.LE..7221) GO TO 426                                   02590
       GO TO 427                                                   02600
43     X=DRAND(8)                                                  02610
       IF (X.LE..20) GO TO 431                                     02620
       IF (X.LE..80) GO TO 432                                     02630
       GO TO 433                                                   02640
411    USERF = 414.04*(X-0.000)+14.5                               02650
       RETURN                                                      02660
412    USERF = 82.78*(X-.1111)+89.5                                02670
       RETURN                                                      02680
413    USERF = 735.29*(X-.1715)+94.5                               02690
       RETURN                                                      02700
414    USERF = 3.04*(X-.1783)+99.5                                 02710
       RETURN                                                      02720
421    USERF = 62.99*(X-0.000)+14.5                                02730
       RETURN                                                      02740
422    USERF = 106.69*(X-.2302)+29.                                02750
       RETURN                                                      02760
```

```
423     USERF = 132.63*(X-.3788)+44.                          02778
        RETURN                                                02788
424     USERF = 52.3*(X-.5216)+64.                            02798
        RETURN                                                02858
425     USERF = 538.5*(X-.6172)+74.                           02818
        RETURN                                                02828
426     USERF = 74.4*(X-.6549)+94.                            02838
        RETURN                                                02848
427     USERF = 16.8*(X-.7221)+99.                            02858
        RETURN                                                02868
431     USERF = 175.*(X-0.8) + 25.8                           02878
        RETURN                                                02888
432     USERF = 58.*(X-.28) + 66.8                            02898
        RETURN                                                02988
433     USERF = 68.*(X-.88) + 98.8                            02918
        RETURN                                                02928
C ** FOR THE C141 ****************                            02938
31      X=DRAND(5)                                            02948
        IF (X.LE..588) CO TO 51                               02958
        IF (X.LE..692) GO TO 52                               02968
        IF (X.LE..923) CO TO 53                               02978
        CO TO 54                                              02988
51      X=DRAND(6)                                            02998
        IF (X.LE..848) CO TO 511                              03888
        IF (X.LE..2166) CO TO 512                             03818
        IF (X.LE..2682) CO TO 513                             03828
        IF (X.LE..4765) CO TO 514                             03838
        IF (X.LE..6135) CO TO 515                             03848
        IF (X.LE..6938) CO TO 516                             03858
        CO TO 517                                             03868
52      X=DRAND(7)                                            03878
        IF (X.LE..895) CO TO 521                              03888
        IF (X.LE..265) GO TO 522                              03898
        IF (X.LE..266) GO TO 523                              03168
        IF (X.LE..555) CO TO 524                              03118
        IF (X.LE..565) CO TO 525                              03128
        IF (X.LE..898) CO TO 526                              03138
        CO TO 527                                             03148
53      X=DRAND(8)                                            03158
        IF (X.LE..1125) CO TO 531                             03168
        IF (X.LE..285) CO TO 532                              03178
        IF (X.LE..415) CO TO 533                              03188
        IF (X.LE..478) CO TO 534                              03198
        IF (X.LE..785) CO TO 535                              03288
        IF (X.LE..795) CO TO 536                              03218
        IF (X.LE..928) CO TO 537                              03228
        CO TO 538                                             03238
54      X=DRAND(9)                                            03248
        IF (X.LE..218) CO TO 541                              03258
        IF (X.LE..468) CO TO 542                              03268
        IF (X.LE..758) CO TO 543                              03278
        IF (X.LE..875) CO TO 544                              03288
        CO TC 545                                             03298
511     USERF = 125.*(X-0.88) + 6.8                           03388
```

```
        RETURN                                  03310
512     USERF = 16.99*(X-.04) + 11.0           03320
        RETURN                                  03330
513     USERF = 58.14*(X-.2166) + 14.0         03340
        RETURN                                  03350
514     USERF = 33.16*(X-.2682) + 17.0         03360
        RETURN                                  03370
515     USERF = 72.99*(X-.4765) + 24.0         03380
        RETURN                                  03390
516     USERF = 24.91*(X-.6135) + 34.0         03400
        RETURN                                  03410
517     USERF = 13.06*(X-.6938) + 36.0         03420
        RETURN                                  03430
521     USERF = 52.63*(X-0.00) + 6.0           03440
        RETURN                                  03450
522     USERF = 17.65*(X-.095) + 11.0          03460
        RETURN                                  03470
523     USERF = 2000*(X-.265) + 14.0           03480
        RETURN                                  03490
524     USERF = 27.68*(X-.266) + 16.0          03500
        RETURN                                  03510
525     USERF = 1006*(X-.555) + 24.0           03520
        RETURN                                  03530
526     USERF = 6.15*(X-.565) + 34.0           03540
        RETURN                                  03550
527     USERF = 36.36*(X-.890) + 36.0          03560
        RETURN                                  03570
531     USERF = 35.56*(X-0.00) + 2.0           03580
        RETURN                                  03590
532     USERF = 54.05*(X-.1125) + 6.0          03600
        RETURN                                  03610
533     USERF = 14.29*(X-.205) + 11.0          03620
        RETURN                                  03630
534     USERF = 90.91*(X-.415) + 14.0          03640
        RETURN                                  03650
535     USERF = 15.87*(X-.470) + 19.0          03660
        RETURN                                  03670
536     USERF = 1000*(X-.785) + 24.0           03680
        RETURN                                  03690
537     USERF = 16.00*(X-.795) + 34.0          03700
        RETURN                                  03710
538     USERF = 50.00*(X-.920) + 36.0          03720
        RETURN                                  03730
541     USERF = 19.05*(X-0.00) + 9.0           03740
        RETURN                                  03750
542     USERF = 8.00*(X-.210) + 13.0           03760
        RETURN                                  03770
543     USERF = 34.45*(X-.460) + 15.0          03780
        RETURN                                  03790
544     USERF = 16.0*(X-.750) + 25.0           03800
        RETURN                                  03810
545     USERF = 32.0*(X-.875) + 27.0           03820
        RETURN                                  03830
C***************************************         03840
```

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C## DETERMINE C141 TURNAROUND TIME ##                                    #3850
C#########################################                                #3860
C                                                                         #3870
C## USERF(4) = POSTFLIGHT + REFUELING + MX PREFLIGHT                      #3880
C                                                                         #3890
4     USERF = RNORM(.7,.08,4)+UNFRM(1.5,2.5,4)+RNORM(.7,.08,4)            #3900
      RETURN                                                              #3910
C#########################################                                #3920
C## DETERMINE C5 TURNAROUND TIME ##                                       #3930
C#########################################                                #3940
C                                                                         #3950
C## USERF(5) = POSTFLIGHT + REFUELING + MX PREFLIGHT                      #3960
C                                                                         #3970
5     USERF= RNORM(1.5,.12,5)+UNFRM(2.6,4.6,5)+RNORM(1.5,.12,5)           #3980
      RETURN                                                              #3990
      END                                                                 #4000

#EOR

;TWO BASE CONCEPT OF STRATEGIC AIRLIFT:  U.S. TO EUROPE                   #4020
;                                                                         #4030
GEN,E K HOLCK,TOBASCO SAUCE,1/23/1981,,N,N,,,N;                           #4040
LIM,11,5,2000;                                                            #4050
NET;                                                                      #4060
      RES/C141(176),1;          C141 AIRCRAFT                             #4070
      RES/C5(53),2;             C5 AIRCRAFT                               #4080
      RES/LEUS(28),3;           LOAD EQUIP IN US                          #4090
      RES/LPUS(70),4;           LOAD PERSONNEL IN US                      #4100
      RES/AC1U(352),5;          C141 AIRCREWS IN US                       #4110
      RES/AC5U(86),6;           C5 AIRCREWS IN US                         #4120
      RES/LEEUR(28),7;          LOAD EQUIP IN EUROPE                      #4130
      RES/LPEUR(70),8;          LOAD PERSONNEL IN EUROPE                  #4140
      RES/AC1E(352),9;          C141 AIRCREWS IN EUROPE                   #4150
      RES/AC5E(86),10;          C5 AIRCREWS IN EURCPE                     #4160
      RES/MP(305),11;           MAINTENANCE PERSONNEL                     #4170
;                                                                         #4180
;INITIALIZE THE MODEL FOR USER FORMATTED DATA:                           #4190
;                                                                         #4200
      CRE,24,24;                                                          #4210
      ACT,,,EV4;                                                          #4220
EV4   EVE,4;                                                              #4230
      TERM;                                                               #4240
;                                                                         #4250
;CREATE A NEW LOAD EVERY 6 MINUTES                                        #4260
;                                                                         #4270
      CRE,.10,,1;                                                         #4280
      ACT,,NNQ(1).LT.1,AS1;                                               #4290
      ACT,,NNQ(2).LT.1,AS2;                                               #4300
AS1   ASS,ATRIB(2)=1;                                                     #4310
      ACT,,,A141;                                                         #4320
;                                                                         #4330
;WAIT FOR A C141. 41.4% WILL REQUIRE LOAD EQUIPMENT                       #4340
;                                                                         #4350
A141  AWA(1),C141/1,1;                                                    #4360
      ACT,,.586,AS3;                                                      #4370
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        ACT,,,.414,AS4;                                          04380
AS3     ASS,ATRIB(3)=0,ATRIB(4)=RNORM(1.3,.2),XX(1)=XX(1)+1;     04390
        ACT,,,ALP;                                               04400
AS4     ASS,ATRIB(3)=.1,ATRIB(4)=RNORM(1.3,.2),XX(2)=XX(2)+1;    04410
        ACT,,,ALE;                                               04420
AS2     ASS,ATRIB(2)=2;                                          04430
        ACT,,1,AC5;                                              04440
;                                                                04450
;WAIT FOR A C5.  65.2% WILL REQUIRE LOAD EQUIPMENT               04460
;                                                                04470
AC5     AWA(2),C5/1,1;                                           04480
        ACT,,.652,AS5;                                           04490
        ACT,,.348,AS6;                                           04500
AS5     ASS,ATRIB(3)=.1,ATRIB(4)=RNORM(3.5,.6),XX(3)=XX(3)+1;    04510
        ACT,,,ALE;                                               04520
AS6     ASS,ATRIB(3)=0,ATRIB(4)=RNORM(3.5,.6),XX(4)=XX(4)+1;     04530
        ACT,,,ALP;                                               04540
;                                                                04550
;WAIT FOR LOAD EQUIP                                             04560
;                                                                04570
ALE     AWA(3),LEUS/1,1;                                         04580
        ACT,,,ALP;                                               04590
;                                                                04600
;WAIT FOR LOAD CREW                                              04610
;                                                                04620
ALP     AWA(4),LPUS/1,1;                                         04630
;                                                                04640
;ACCOUNT FOR LOADING TIME.  ATRIB(4) IS LOADING TIME, ATRIB(3)   04650
;IS THE TIME IT TAKES THE LE TO GET TO THE ACFT.                 04660
;AFTER FREEING LE AND LP, ACFT ARE READY WITH CARGO AND NEED AIRCREWS. 04670
;                                                                04680
        ACT,ATRIB(3)+ATRIB(4);                                   04690
        GOO,1;                                                   04700
        ACT,,ATRIB(3).NE.0,FLE;                                  04710
        ACT,,ATRIB(3).EQ.0,FLP;                                  04720
FLE     FRE,LEUS/1;                                              04730
        ASS,XX(5)=XX(5)+1;                                       04740
FLP     FRE,LPUS/1,1;                                            04750
        ACT,,ATRIB(2).EQ.1,C1RC;                                 04760
        ACT,,,C2RC;                                              04770
C1RC    COL,INT(1),C141 CARGO READY;                             04780
        ACT,,,AC1U;                                              04790
C2RC    COL,INT(1),C5 CARGO READY;                               04800
        ACT,,,AC5U;                                              04810
;                                                                04820
;WAIT FOR C141 AIRCREWS                                          04830
;                                                                04840
AC1U    AWA(5),AC1U/1;                                           04850
        ACT,,,AS7;                                               04860
;                                                                04870
;WAIT FOR C5 AIRCREWS                                            04880
;                                                                04890
AC5U    AWA(6),AC5U/1;                                           04900
        ACT,,,AS7;                                               04910
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;                                                           04920
;START CREW DUTY DAY 2 HOURS BEFORE REPORT TO AIRCRAFT.  THIS 04930
;ACCOUNTS FOR CREW ASSEMBLY, BRIEFING. ETC.                 04940
;                                                           04950
AS7   ASS,ATRIB(5)=TNOW-2.0;                                04960
      ACT,UNFRM(1.0,1.5);                                   04970
      GOON,1;                                               04980
;                                                           04990
;15% OF THE AIRCRAFT WILL REQUIRE PRE-TAKEOFF MAINTENANCE.  05000
;TIME DELAYED = USERF(1).                                   05010
;                                                           05020
      ACT,,.85,AS8;                                         05030
      ACT,USERF(1),.15,AS8;                                 05040
;                                                           05050
;FLIGHT TIME TO EUROPE.  ANOTHER LOAD OF BREAD, BLANKETS AND 05060
;BULLETS FOR THE BOYS AT THE FRONT.                         05070
;                                                           05080
AS8   ASS,ATRIB(4)=RNORM(7./,.2);                           05090
      ACT,ATRIB(4),,GO2;                                    05100
GO2   GOON,2;                                               05110
;                                                           05120
;THESE TWO STATEMENTS FOLLOW THE AIRCRAFT FOR UNLOADING,TURNAROUND, 05130
;AND FLIGHT BACK TO THE US. (SEE "AIRCRAFT ROUTINE IN EUROPE") 05140
;                                                           05150
      ACT,,ATRIB(3).EQ..1,ALEE;                             05160
      ACT,,ATRIB(3).EQ.0,ALPE;                              05170
;                                                           05180
;THESE TWO STATEMENTS FOLLOW THE AIRCREW AFTER LANDING.  CREWS 05190
;GO THRU DEBRIEFING, ETC., THEN ARE ALLOWED 12 HOURS CREWREST 05200
;BEFORE BEING MADE AVAILABLE AGAIN.                         05210
;                                                           05220
      ACT,UNFRM(1.0,1.5),ATRIB(2).EQ.1,CO1;                 05230
      ACT,UNFRM(1.0,1.5),ATRIB(2).EQ.2,CO2;                 05240
CO1   COL,INT(5),C141 DUTY DAY;                             05250
      ASS,XX(6)=XX(6) + ATRIB(4),XX(8)=XX(8)+USERF(3);      05260
      ACT,12.0;                                             05270
      FRE,AC1E/1;                                           05280
      TERM;                                                 05290
CO2   COL,INT(5),C5 DUTY DAY;                               05300
      ASS,XX(7)=XX(7) + ATRIB(4),XX(9)=XX(9)+USERF(3);      05310
      ACT,12.0;                                             05320
      FRE,AC5E/1;                                           05330
      TERM;                                                 05340
;                                                           05350
;AIRCRAFT ROUTINE IN EUROPE:                                05360
;                                                           05370
ALEE  AWA(7),LEEUR/1;                                       05380
      ACT,,,ALPE;                                           05390
ALPE  AWA(8),LPEUR/1;                                       05400
;                                                           05410
;UNLOAD THE ACFT                                            05420
;                                                           05430
      ACT,USERF(2),,GO7;                                    05440
GO7   GOON,1;                                               05450
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        ACT,,ATRIB(3).EQ..1,FLEE;                                           05460
        ACT,,ATRIB(3).EQ.0,FLPE;                                            05470
FLEE    FRE,LEEUR/1;                                                        05480
        ACT,,,FLPE;                                                         05490
FLPE    FRE,LPEUR/1;                                                        05500
        COL,INT(1),TRANSIT TIME;                                            05510
;                                                                          05520
;AFTER THE ACFT ARE UNLOADED, SEPARATE THE C141S FROM THE C5S               05530
;AND PREPARE FOR THE RETURN TRIP.                                          05540
;                                                                          05550
        ACT,,ATRIB(2).EQ.1,C05;                                            05560
        ACT,,ATRIB(2).EQ.2,G06;                                            05570
C05     C00,1; ***********************************************************  05580
;                                                                          05590
;THIS ACTIVITY INCLUDES POSTFLIGHT, REFUELING, AND MX PREFLIGHT OF C141S    05600
;                                                                          05610
        ACT,UNFRM(2.0,4.0);                                                05620
;                                                                          05630
;NOW WAIT FOR A C141 AIRCREW.                                              05640
;                                                                          05650
        AWA(9),AC1E/1,1;                                                   05660
;                                                                          05670
;AGAIN, 15% OF THE C141S REQUIRE SOME PRE TAKEOFF MAINTENANCE.              05680
;                                                                          05690
        ACT,UNFRM(.5,1.5),,.15,AS10;                                       05700
        ACT,,,.85,AS10;                                                    05710
AS10    ASS,ATRIB(4)=RNORM(9.3,.2),XX(6)=XX(6) + ATRIB(4),1;                05720
;                                                                          05730
;FLIGHT BACK TO THE US.                                                    05740
;                                                                          05750
        ACT,ATRIB(4);                                                      05760
;                                                                          05770
;AFTER 13.5 HOURS, CREWS ARE MADE AVAILABLE FOR US-TO-EUROPE               05780
;FLIGHTS.  THIS INCLUDES 12 HOURS FOR CREWREST.                            05790
;                                                                          05800
        C00,2;                                                             05810
        ACT,13.5,,FA1U;                                                    05820
        ACT,,,C03;                                                         05830
FA1U    FRE,AC1U/1;                                                        05840
        TERM;                                                              05850
C06     C00,1; ***********************************************************  05860
;                                                                          05870
;THIS ACTIVITY INCLUDES POSTFLIGHT, REFUELING, AND MX PREFLIGHT OF C5S      05880
;                                                                          05890
        ACT,UNFRM(2.0,4.0);                                                05900
;                                                                          05910
;NOW WAIT FOR A C5 AIRCREW.                                                05920
;                                                                          05930
        AWA(10),AC5E/1,1;                                                  05940
;                                                                          05950
;HERE, 30% OF THE C5S REQUIRE SOME PRE-TAKEOFF MAINTENANCE.                 05960
;                                                                          05970
        ACT,UNFRM(.5,1.5),,.3,AS11;                                        05980
        ACT,,,.7,AS11;                                                     05990
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AS11   ASS,ATRIB(4)=RNORM(9.3,.2),XX(7)=XX(7) + ATRIB(4),1;              06000
;                                                                        06010
;FLIGHT BACK TO THE US.                                                  06020
;                                                                        06030
       ACT,ATRIB(4);                                                     06040
;                                                                        06050
;AFTER 13.5 HOURS, CREWS ARE MADE AVAILABLE FOR US-TO-EUROPE            06060
;FLIGHTS.  THIS INCLUDES 12 HOURS FOR CREWREST.                          06070
;                                                                        06080
       GOO,2;                                                            06090
       ACT,13.5,,FA5U;                                                   06100
       ACT,,,GO3;                                                        06110
FA5U   FRE,AC5U/1;                                                       06120
       TERM;                                                             06130
;THIS STREAM FOLLOWS THE ACFT.  50% OF THEM REQUIRE NO MAINTENANCE       06140
;AND ARE MADE AVAILABLE FOR FLIGHT (GO4).  THE OTHER HALF MUST           06150
;GO THRU MAINTENANCE AS FOLLOWS:                                         06160
GO3    GOON,1;                                                           06170
       ACT,,.5,GO4;                                                      06180
       ACT,,.5,EV1;                                                      06190
;               1.  DETERMINE MX TIME                                    06200
EV1    EVE,1;                                                            06210
;               2.  DETERMINE MX PERSONNEL REQ'D                         06220
       EVE,2;                                                            06230
;               3.  DETERMINE DELAY DUE TO SUPPLY                        06240
       EVE,3;                                                            06250
       ACT/1,ATRIB(5),,AMP;                                              06260
AMP    AWA(11),MP/ATRIB(4);                                              06270
       ACT/2,ATRIB(3);                                                   06280
       FRE,MP/ATRIB(4);                                                  06290
;                                                                        06300
;AIRCRAFT TURNAROUND AND RETURN TO ACFT RESOURCE WHERE IT                06310
;WAITS FOR CARGO (SEE BEGINNING OF NETWORK).                             06320
;                                                                        06330
GO4    GOON,1;                                                           06340
       ACT,USERF(4),ATRIB(2).EQ.1,F141;                                  06350
       ACT,USERF(5),ATRIB(2).EQ.2,FC5;                                   06360
;                                                                        06370
;ONCE THE ACFT IS FIXED, IT IS MADE AVAILABLE FOR USE.                   06380
;                                                                        06390
F141   FRE,C141/1;                                                       06400
       TERM;                                                             06410
FC5    FRE,C5/1;                                                         06420
       TERM;                                                             06430
       END;                                                              06440
INIT,0,720;                                                              06450
SEEDS,-124397822910957(1),-3467133363389(2),-79654468614381(3);         06460
SEEDS,-184170232136813(4),-280033029935085(5),-147959512963949(6);      06470
SEEDS,-125894583854829(7),-150477775663725(8),-227874746727917(9);      06480
SEEDS,-82174077946221(10);                                              06490
MONTR,SUMRY,24.,24.;                                                     06500
TINST,XX(1),C141 WOUT LE;                                               06510
TINST,XX(2),C141 WITH LE;                                               06520
TINST,XX(3),C5 WITH LE;                                                 06530
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TIMST,XX(4),C5 WOUT LE;                                    06540
 TIMST,XX(5),NUMBER LE FREED;                              06550
 TIMST,XX(6),C141 FLY TIME;                                06560
 TIMST,XX(7),C5 FLY TIME;                                  06570
 TIMST,XX(8),C141 TONNAGE;                                 06580
 TIMST,XX(9),C5 TONNAGE;                                   06590
 FIN;                                                      06600

*EOR
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Appendix B

Glossary

ALM--Airlift Loading Model

Bulk Cargo--Any cargo that can be loaded on a 463L pallet
     without exceeding the useable dimensions of the
     pallet

MAC--Military Airlift Command

MACRO-14--MAC Resource Optimization model number 14; a large
     simulation model of the MAC airlift system

NATO--North Atlantic Treaty Organization

NMCM--Not Mission Capable due to Maintenance

NMCS--Not mission Capable due to Supply

Outsize Cargo--Cargo that exceeds the capability of a C-141
     aircraft and requires the use of a C-5 aircraft

Oversize Cargo--A single item that exceeds the useable dimen-
     sions of a 463L pallet

SLAM--Simulation Language for Alternative Modeling (Ref 21)

UTE Rate--Aircraft utilization rate; average flying hours
     per day for all aircraft being considered

WRM--War Reserve Material; critical aircraft spare parts
     that are maintained in designated war reserve
     spares kits

Vitas of the Authors

Captain Eric Kalei Holck was born on 21 December 1952 in Honolulu, Hawaii. He graduated from the Kamehameha Schools in 1970 and went on to the U.S. Air Force Academy in Colorado Springs. Upon graduation from the Academy in 1974, he received his Bachelors of Science Degree in Engineering Mechanics and was commissioned into the U.S. Air Force. He attended pilot training at Laughlin AFB, Texas in 1974 where he earned his pilot wings. He then flew KC-135s out of Grand Forks AFB, North Dakota from January 1976 until August 1979 when he was assigned to the Strategic and Tactical Sciences program at the Air Force Institute of Technology.

Captain Holck is married to the former Miss Katherine Angela Cheselski of Grand Forks, North Dakota. They have one daughter, named Erin Ka'anelaomaile Holck.

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Robert W. Ticknor was born in Austinburg, Ohio on December 28, 1950. He graduated from high school in Geneva, Ohio in 1969. In 1973 he graduated from the United States Air Force Academy with a Bachelor of Science degree in Chemistry and a commission in the United States Air Force. He completed navigator training in May 1974 and was assigned to Charleston AFB, SC in the C-141. While at Charleston, he was an instructor and then a standardization flight examiner navigator. He entered the School of Engineering, Air Force Institute of Technology, in August 1979. He is married to the former Jenny H. Young of Greenville, SC. They have twin sons, Robert and Brian.

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